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AN AIR POLLUTION IMPACT METHODOLOGY FOR AIRPORTS

PHASE 1

ARGONNE NATIONAL LABORATORY

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It has been demonstrated that large airports have a direct impact on environmental
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point for urban development and industrialization. This report addresses the air pollu-
tion impact of an airport and its environs. A methodology is presented for integrating
the air pollution impact of an airport and its associated ground-support activities with
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for decisions related to airport site selection and for the development of land surround-
ing the site. Procedures for estimating airport-related air pollutant emissions are de-
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which provide environmental insults. The procedures are general and applicable to either
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AN AIR POLLUTION IMPACT METHODOLOGY FOR AIRPORTS AND ATTENDANT LAND USE

January 1973

by

J. E. Norco, R. R. Cirillo,

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ABSTRACT

It has been demonstrated that large commercial airports not only have a significant direct impact on environmental quality as a result of activities related to aircraft operations, but in many cases also induce a substantial indirect impact by providing a focal point for urban development and industrialization. A comprehensive assessment of the environmental consequences of siting a major airport facility must therefore take account of both the direct and indirect impacts that can be expected to result.

Although large airports and the activities that tend to cluster about them generally produce substantial emissions to all media as well as a variety of the categorical pollutants, this report addresses only one aspect of the impact assessment problem - the airport and its environs as an aggregate source of air pollution. A methodology is presented for integrating the air pollution impact of an airport and its associated ground support activities with that of the induced urban development in its vicinity to provide a quantitative basis for decisions related to airport site selection and for the development of the land surrounding the site. Procedures for estimating airport-related air pollutant emissions are defined. The latter can be transformed into air quality estimates through the use of "rollback" analysis or atmospheric dispersion models.

The impact assessment methodology is based on an approach which can be adapted readily to other media and to various categorical pollutants. This flexibility is achieved through a general protocol for identifying, isolating, and quantifying an array of airport-related and urban activities which provide environmental insults. The impact assessment methodology is intended to be general and is applicable to either existing or proposed airport facilities. It was developed and field tested using data from the proposed St. Louis airport at Waterloo-Columbia, Illinois, from the Chicago O'Hare International Airport, and from several other existing facilities.

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1.0 Introduction

This report presents a methodology for assessing the air pollution impact of major commercial airports and the urban activities that surround them. The ultimate goal of this work is to enable airport, transportation and comprehensive planners to incorporate environmental considerations into the site selection and design of airport facilities and into planning for the development of the land in the airport environs. The first phase of the EPA-sponsored program to develop this methodology is focused on the assessment of air pollution emissions that are the direct and indirect result of airport activities.

1.1 The Need for Improved Airport Environmental Impact Analysis

Environmental Impact Statements

The growth of air travel and the resultant development and upgrading of airport facilities have provided new challenges in planning for the needed expansion while minimizing undesirable environmental effects. The mechanism presently employed for the integration of environmental assessment into the planning process is the Environmental Impact Statement which is required under Section 102 of the National Environmental Policy Act (NEPA) of 1969. This Act requires assessment of environmental effects of proposed airport and other development actions involving federal funds. It is unfortunate, however, that the requirements of the NEPA cannot be adequately met with current techniques of quantitatively evaluating the impact of an airport site and its surrounding development. Typically, the Environmental Impact Statement will contain an elaborate description of why the facility is needed and how it will be constructed, but, generally, there are meager descriptions of the actual environmental insults that will result from the operation of the facility.

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In many cases, nondescript terminology is used to explain in very qualitative terms the impact of the proposed facility. For example, terms such as "minimal, minor, not expected to be appreciable," etc., are used to describe environmental effects such as the degradation of air and water quality, noise, and so on. It is not therefore surprising that most of the airport Environmental Impact Statements developed to date fail to provide a satisfactory analysis of potential problem areas. This inadequacy reflects both a lack of understanding of environmental problems and a lack of quantitative tools to perform the necessary analyses. Furthermore, there is increasing evidence that environmental consideration are being used by special interest groups as a means of deterring airport development. The lack of adequate impact methodologies compounds this problem, since airport developers are hard pressed to confirm or refute contentions that environmental quality standards will be violated in airport environs.

Growth of Air Travel

The growth of aeronautical activity and the need for new airports and facility expansions is evident. The National Aviation System Plan[9] issued by the Federal Aviation Administration (FAA) provides for the orderly acquisition of new facilities and equipment at a rate sufficiently great to satisfy immediate requirements as well as to provide for future demands, but in recent years, the facility construction has failed to keep pace with the changes required by aircraft development and generated by increases in the demand for air transport. The National Airport System identified by the FAA is composed of approximately 3,240 airports included in the 12,070 existing civil airports in the United States. A need for continuing expansion is foreseen throughout the next decade, since flight activity for 1982 is projected to double that of 1971. The FAA recognizes the need through 1982 for 1,410 additional airports, including 112 to accommodate both air carrier and general aviation activity and 1,298 for the exclusive use of general aviation. It is expected that an expenditure in excess of $4 billion will be required to improve existing airports and to develop new facilities.

The Federal Aviation Administration recognizes that environmental constraints may present serious potential problems for airport development programs. According to the National Aviation System Plan, "Unless solutions can be found, too many of the nations large airports may be precluded from development to their full potential and other needed airports may not be built. These problems include environmental factors such as aircraft noise, compatible land use, airport access and ecology." Solutions to these problems cannot be achieved unless the magnitude of their impacts can be adequately described.

1.2 Objectives of the Study

The foregoing discussion has suggested deficiencies and needs in current airport environmental impact assessment procedures. The studies reported here were initiated in order to provide airport and land use planners with the tools necessary to perform comprehensive environmental evaluations of airport sites and to prepare environmentally sensitive land use plans for the surrounding area. This study focuses on the air pollution component of the airport environmental impact evaluation process.

The methodologies described here are designed to yield airport and related land use air pollutant emission estimates based on readily available information. The methods employed are applicable to proposed or existing airports. In the case of new facilities or expansions of existing installations, the data necessary for an impact evaluation can be derived from engineering studies, air transport forecasts, and regional land use and transportation planning data. For existing facilities, actual observations, land use surveys, or historical records are employed. The coupling of these emission estimates to an air quality model for eventual air quality impact and evaluation of alternatives was not performed as part of this study; however, these tasks are scheduled for the second phase of the program. The data system design and the matching of data formats that are necessary to complete this interface have been completed as a part of the effort reported here.

In addition to the generalized methodologies presented in this report, specific results were obtained for the proposed St. Louis airport at Waterloo-Columbia, Illinois, and for Chicago's O'Hare International Airport. These two airports were used as demonstration sites for the development and field testing of the methods, although information derived from other major airports was utilized as well. A significant portion of the study was devoted to a historical case study of land use in the vicinity of O'Hare. This study provided (1) a basic understanding of airport area development and (2) a foundation for the development of land-use-based air pollution emission estimates.

A summary of the analytical methods and models employed is presented in Table 1.1. It is expected that the complete package of procedures developed during the course of this program will be reduced to a fairly simplified workbook format that can easily be integrated into the routine airport site selection and environmental impact analysis process.

1.3 Land Use Implications

The development of airport facilities clearly represents a substantial public investment equivalent, for example, to the construction of a major highway system. The consequences are, in many respects, similar; i.e., the construction of a new airport tends to have a significant effect on the use and value of adjacent land. It tends to generate, divert, or eliminate travel that would otherwise not have been affected; it creates employment opportunities; it

Table 1.1

Phase I Program Output Summary

Output	Parameters Included	Sources of Information
1. Airport Activity Model	Air passenger movements Aircraft movements Aircraft mix Access traffic volume	Engineering studies Existing airport data
2. Airport Rate of Emissions of Air Pollutants	Aircraft Ground service vehicles Access traffic Stationary sources	Airport Activity Model and emission factors
3. Land Use Model	Projected land development surrounding the airport.	Census or aerial photo data Regional or Airport Master Plan
4. Land Use Rate of Emissions of Air Pollutants	Spatially distributed emission map	Land Use Model and land-use-based emission factors
5. Climatology Model-Evaluation of Air Pollution Potential	Meteorological data	U.S. Weather Bureau data tapes

attracts certain industrial and commercial activities; and it may promote or deter the development of communities in its vicinity. Moreover, just as a highway system tends to induce a land use pattern that in turn creates a demand for resources such as energy, water, and feeder transportation facilities, so an airport creates both a direct demand for such resources and, through its influence on community development and land use, an equivalent indirect demand which must be satisfied through a reallocation of regional resources.

It follows that a major airport, like a major highway facility, is likely to have a substantial direct and indirect effect on local environmental quality which should be assessed as a routine part of any airport site evaluation study. With the significant exception of aircraft noise, however, detailed environmental impact evaluation has not normally been undertaken prior to airport construction. This can be attributed partly to the fact that aircraft noise is the only environmental effect associated with airport operation that has hitherto aroused vigorous public response and partly to the fact that no public agency has, until recently, possessed the authority or responsibility to police aircraft operation from the environmental standpoint. The FAA is primarily concerned with aircraft noise as a phenomenon which can inhibit the realization of the National Airport System Plan and compromise the very substantial federal investment in airport facilities.

With the advent of the current national emphasis on environmental protection, the federal government has addressed other aspects of the airport environmental problem. For example, the EPA has recently proposed air pollutant emission standards for aircraft engines. Although federal controls of this kind are undoubtedly desirable, they fail to address the central requirement that an assessment of the total environmental impact of building and operating a major airport and developing the surrounding land should be an integral part of the site evaluation procedure as are aircraft safety studies or terminal building design.

From the standpoint of environmental protection, an airport can be viewed as a source of noise, air and water pollution, and solid waste. In addition, an airport is responsible for the consumption of substantial amounts of energy (electric and fuel) which results in the discharge of considerable quantities of waste heat and air pollution. The major direct sources of noise and air pollution are, of course, the aircraft themselves; however, the fact that an airport is served by major access roads and incorporates parking and holding facilities for motor vehicles indicates that it may also constitute a significant source of ground vehicle noise and air pollution. Moreover, the facility serves as a focal point for the concentration of certain commercial and industrial activities that would not otherwise be present.

For these reasons, the airport planner must now enlarge his view of what constitutes significant considerations in airport sizing, location, and operational characteristics. The need for coordination or regional growth planning and total transportation system development with airport site planning is accentuated. Alternatives related to minimizing the adverse environmental impacts of the urban/industrial development adjacent to an airport as well as those of the airport itself must be considered. The "environmentally sensitive" land use plan is likely to become a standard component of the overall airport planning process.

1.4 Review of the Methodology

The impact evaluation methodology presented in this report is based on the identification and isolation of air pollution producing activities, both within the airport and in its environs. These activities are then quantified and transformed into emission estimates, based on state-of-the-art source emission factors. Airport-related activities have been functionally separated into two broad categories; those which occur within the airport boundaries, and those associated with the land use and ground transportation activities which are external to the airport and are presumed to be, to some extent, related to or induced by the presence of the airport facility. Each of these activities is quantified in terms of an easily determined or measurable descriptor. Among the activities which are associated with air pollutant emissions within an airport are included:

1. Aircraft
2. Ground service vehicles
3. Access traffic
4. Fuel distribution
5. Point sources within the airport
   (i.e., heating plant)

In the case of a proposed airport, the independent or driving variables used to develop activity level estimates are the projected number of enplaned passengers, the air cargo demand, and aircraft activity and mix estimates. For existing facilities, the same driving variables are required; however, historical observations are substituted for estimated activity levels. The activity levels corresponding to the area surrounding the airport are estimated on the basis of a land classification scheme (residential, commercial, institutional, industrial, etc.). The level of activity or development intensity associated with each of these land use categories is derived from the comprehensive master plans for the proposed airport site area or from projections derived from census data and aerial photographic techniques. This information is utilized to convert activity level estimates based on land use into air pollution emission estimates.

Report Contents

Section 2 describes the use of standard engineering and planning studies that normally form the basis for an analysis of a proposed airport facility. The engineering studies that were conducted for the proposed St. Louis airport at Waterloo-Columbia, Illinois, are summarized and reviewed.

Section 3 covers the derivation of airport-specific air pollution emission estimating procedures.

In Section 4, the land use activity and air pollution emission estimation methodology is described. The results of a retrospective land use case study at O'Hare Airport are also presented.

Section 5 presents results and compares the airport and land use emission estimation methodologies.

Section 6 provides a case study of the meteorological/air pollution potential of the proposed St. Louis airport site. The data reviewed and analyzed includes wind speed and direction, persistence, mixing height, actual air quality measurements and modeling results.

Section 7 outlines the current status of and required interfacing with airport air quality models now available at Argonne. Three models are currently available: (1) Argonne/FAA Airport Model; (2) Northern Research and Engineering Corp. Model; and (3) Systems, Science, and Software Photochemical Model.

Section 8 is a summary of conclusions and observations.

Appendix A contains a detailed description of an aerial photographic technique that is appropriate for generating land use data.

Appendix B presents the historical land use trends in the 4 townships adjacent to O'Hare International Airport.

2.0 REVIEW OF ENGINEERING STUDIES

Airport engineering studies are those documents drawn up to satisfy the technical needs of the decision makers charged with the responsibility of providing air transportation to a community. With respect to the construction of new airports, the three basic questions which these studies are designed to answer are: (1) "Is it necessary?"; (2) " Where should it be built?"; and (3) "What should it look like?" With the recent enactment of the National Environmental Policy Act, one additional question was added to the list: "What will be its effect on the environment." The document designed to provide that answer is the Environmental Impact Statement.

The purpose of this section is to take the proposed new St. Louis airport as an example and review the information that is generally available in airport engineering studies. Since the ultimate goal of this study is to develop a methodology to assess the air quality impact of a major air carrier airport and its surrounding development, and since the Environmental Impact Statement is commissioned to provide some of this information, it, too, will be reviewed and comments will be offered as to its effectiveness in meeting its charge. It was originally anticipated that at least part of the master plan for the new St. Louis airport would also be available for review. Unfortunately, the final decision on the airport site has not yet been made and, as such, the master plan has not yet been drawn up.

2.1 History of the Project

Based upon conversations with those involved in the development of the plans for a new St. Louis airport, the City of St. Louis was the first to sense a need for an expansion of the commercial air transport facilities in the region. The airport consultant firm of Landrum & Brown, Cincinnati, did the first study of the capacity of the existing airport serving St. Louis, Lambert Field. In 1968, the city decided that Lambert would probably not be able to handle the projected growth in air traffic and could not be expanded to meet the need. The firm of Horner & Shifrin was retained to do a site selection study for a new airport. The firm was commissioned to choose a site without regard to its location with respect to the Illinois-Missouri boundary. The study evaluated six sites in Illinois and six in Missouri. The conclusion of that initial work which was published in August,1969,[7] was that the best site was near the towns of Columbia and Waterloo, Illinois, approximately 16 miles from the St. Louis central business district (see Fig. 2.1).

The firm of R. Dixon Speas was hired by the State of Illinois to do an independent site selection study. Their report published in October 1970,[2] concluded the same as the original Horner & Shifrin work.

Following the Speas work, the Illinois legislature created the St. Louis Metropolitan Area Airport Authority to be the officiating body for all matters related to the airport. The Authority retained Speas to do a confirmatory study[8] which again concluded that the Columbia-Waterloo site was best suited for airport development.

With the State of Illinois taking most of the initiative up to this point, the State of Missouri commissioned its own study. This was carried out by the Northrop Airport Development Corporation (NADC) and published in August, 1971[3]. It concluded that the Columbia-Waterloo site, along with two sites in Missouri near Dardenne and near St. Charles, merited top consideration for airport location.

The McDonnell-Douglas Aircraft Corp., which is a major employer in St. Louis and which has one of its main plants located at Lambert Field, undertook its own study in 1971.[4] It concluded that expansion of Lambert,

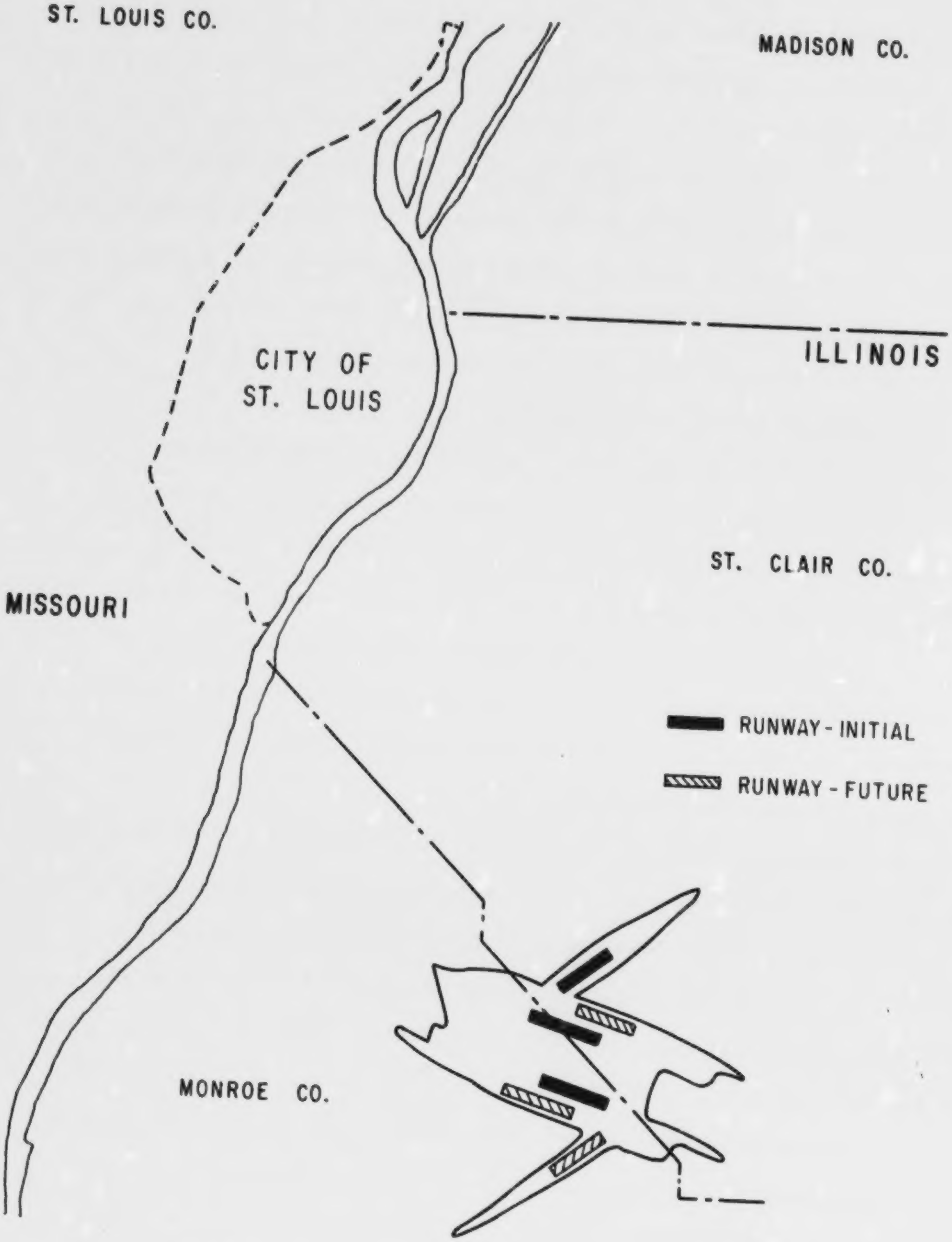

ST. LOUIS CO.
MADISON CO.
CITY OF ST. LOUIS
ILLINOIS
ST. CLAIR CO.
MISSOURI
RUNWAY - INITIAL
RUNWAY - FUTURE
MONROE CO.

Fig. 2.1 Columbia - Waterloo Site
Proposed New St. Louis Airport

along with the introduction of STOL/VTOL aircraft into commercial service would provide more than adequate facilities to serve the St. Louis area through some future date.

would provide more than adequate facilities to serve the St. Louis area.

The Environmental Impact Statement[1] for the St. Louis airport was prepared by the St. Louis Metropolitan Area Airport Authority and submitted to the East-West Gateway Coordinating Council for A-95 review. The draft impact statement has also been submitted to the Federal Aviation Administration in support of the Columbia-Waterloo site as the best choice for the new airport location.

At the time of this report, the final decision on the airport site has not yet been made by the FAA. There are two groups trying to sway the FAA decision and their polarization has increased with each suceeding study. The central issue which divides them is the location of the airport, that is, whether it is to be in Illinois or in Missouri. It is an indication of the economic progress associated with the coming of an airport that both groups are working furiously to have the airport located on their side of the Mississippi River. The State of Missouri has recently formed its own Airport Authority and has applied to the East-West Gateway Coordinating Council for a study grant for the purpose of selecting an airport site in Missouri. This request was denied by EWGCC as being redundant.

A public hearing held in St. Louis on August 1, 1972, by the FAA was designed to air both sides of the controversy and provide an opportunity to form a consensus of public opinion before the final site choice was made. The hearing brought the governors of both Illinois and Missouri together to argue for the site to be located in their respective states.

An airport referendum was placed on the November, 1972, ballot in Missouri. The voters cast their ballots overwhelmingly to continue the use of Lambert Field and to build a new airport, if and when needed, in Missouri.

With all of the engineering studies, the political considerations, and the public opinion differences before them, the FAA is faced with the difficult task of choosing a site to serve St. Louis air transport needs. The decision is expected shortly.

Despite all the uncertainty about the airport site, it is still possible to develop an air quality analysis for the St. Louis airport, independent of its final site. This is because the methodology developed will be general and the activity levels used to make the calculations will be valid for any site. There are likely to be some differences, however, in the meteorological air pollution potential evaluations. For the purposes of this report, it will be assumed that the airport is to be located at the Columbia-Waterloo site whenever it is necessary to make some statements that are site-specific. This will be true mainly in Section 6.0.

2.2 Engineering Study Survey

Horner & Shifrin Study

The original Horner & Shifrin Study[7] is a brief survey of possible sites for a new airport to serve St. Louis. The report does not attempt to justify the need for a new airport but only evaluates alternative sites. The twelve sites considered are judged on the basis of "environment, air space clearance, accessibility, terrain, land cost." The environment evaluation is not taken to mean impact on the natural environment, but rather means the general location of the airport with respect to populated areas. Since this study was intended to be an initial overview of the possible sites, it does not contain any detailed information which could be extracted for use in a thorough environmental impact analysis.

Speas Study

The two studies done by Speas[2,8] were not available for first-hand review. The Environmental Impact Statement[1] did, however, utilize the Speas work as the basis for its conclusions and presented a significant amount of data from the Speas reports.

The studies present an extensive review of air passenger and air traffic forecasts, and proceed to the justification of the need for a new airport based on this data. Projections of aircraft activity and mix, and diurnal patterns of activity are developed. This is the same data that is necessary to begin an air quality analysis.

Extensive analyses of the aviation requirements (i.e., airspace clearance, physical obstructions, etc.) are presented and evaluations of alternative site development costs are discussed. This information is not fundamentally necessary to conduct the environmental analysis.

Based on references in the Impact Statement, the Speas study attempts to answer the first three questions of airport need, airport location, and airport design in some detail. The environmental impact analysis is based primarily on the noise effects and little, if any, analysis is done on air quality impacts. There is however, a wealth of airport activity data which which can be used to develop the air pollutant emission estimates. Since the Impact Statement seems to use the Speas work as its baseline, it will be used here also.

NADC Study

The Northrop report[3] is an extensive study that is equal in scope to the Speas studies. Airport need justification is based on projected air traffic growth and regional economic development. The procedures used are outlined in some detail and the data is easily transformed into required format for environmental analysis.

Additional evaluations of airspace, site engineering requirements, ground access convenience, and airport economic benefits are included, and a tradeoff analysis of alternative sites is performed.

An environmental evaluation of the alternative sites is included in this study. The impacts on flora and fauna, air quality, noise levels, water quality, and solid waste are discussed briefly. The air quality analysis is based primarily on meteorological conditions prevelant in the area and the existing air quality. No calculations of projected air pollutant emissions from the airport are displayed and the only reference to the overall impact is to the effect that federal air quality standards are not expected to be exceeded.

McDonnell Study

The McDonnell Study[4] is substantially briefer than either the Speas or NADC studies, and is concerned primarily with evaluating the ability of Lambert Field to handle the projected air traffic increases. The report focuses mainly on estimating aircraft activity for Lambert and displaying the alternative solutions for matching capacity to demand. Even though the report deals mainly with Lambert Field, the air traffic forecasts can still be used in the environmental analysis.

No environmental analysis is undertaken in the McDonnell Study.

2.3 Environmental Impact Statement Review

In this section, in addition to reviewing the Impact Statement, several suggestions for improving its ability to display environmental impact will be offered.

The Environmental Impact Statement for the St. Louis airport[1] contains a brief discussion of the expected air quality impact of the proposed Columbia-Waterloo site. The report singles out nitrogen oxides, carbon monoxide, hydrocarbons, particulates and sulfur oxides as the primary air pollutants of concern. (It should be noted that the Statement seems to link jet fuel odors with sulfur oxides. The general consensus, however, is that odors are hydrocarbon-related.)[43]

The Statement itemizes the important emission sources to be aircraft, engine overhaul test cells, fuel handling, jet fuel dumping, and ground vehicles. To that list, it is felt that the airport heating plant should be added since it can be a significant contributor, depending on the fuel used, to the overall emission load. Fuel dumping is not expected to be significant in the near future because even now airlines are implementing their own regulations to eliminate this practice; this being done in anticipation of government regulations.

A calculation of 1990 emissions for each of the sources is presented in the Statement. Although the actual numbers are comparable to what is calculated in this study, the presentation of this one set of figures is not sufficient to make any definitive statements about the air quality impact of the airport. A display of how the emissions will vary through the forecast period, where the emissions are coming from, diurnal emission patterns, and emission trends is required for planners to assess actual impacts. Despite the number of qualitative statements made which indicate that the air quality situation is controllable, there is insufficient quantitative data to support the conclusions. A substantial improvement in the ability of the Impact Statement to reflect the air pollution situation could be had by increasing the scope and detail of the calculations presented.

The Impact Statement summarizes the aniticipated air quality effects by stating that the airport is not expected to result in a violation of federal air quality standards and that improvements in aircraft and ground vehicle emission controls will further reduce the airport's impact on the air environment. As before, however, there is not enough quantitative demonstration of the validity of these statements.

There are several additional important items needed to complete the analysis that have not been included in the Impact Statement. The first is the effect on regional air quality of the surrounding land development that will result from the improved transportation system provided by the airport and its access roads. A later part of this study will show that airports generate significant development of the land around them and that the emission densities of this land use can equal and exceed the emissions from the airport itself. The quality of the air in the airport vicinity will be as much or more a function of the attendant land use as it is of the airport activity. Because of this, the regional effects must be considered in developing a strategy to meet air quality standards. The airport itself may not result in violated standards but the airport, plus surrounding development, almost certainly will if no controls are imposed.

A second important item which should have been considered is the quality of the air on the airport grounds. While, as the Impact Statement notes, airports may contribute on the order of only 1% of regional air pollutant emissions, they can produce sufficient concentrations of pollutants on the site itself to result in a local violation of air quality standards. Since the standards include a one-hour measurement period, and since it is easily possible for people to spend an hour or more at the airport, the local impacts cannot be ignored.

A third item that needs mention is the effectiveness of various control alternatives in keeping a check on the various emission sources. Some reference is made to controlling airport emissions by operational restraints placed on aircraft. It is not clear how much improvement could be realized based upon the presented data. No statement is made about land use controls needed to attain regional air quality goals.

The final point of emphasis is that emission data by itself is not a measure of air quality. Emission rates must be translated into air quality via dispersion modeling or some other technique in order to actually provide an estimate of the impacts. Even the extensive emission calculations carried out in this study do not transform directly into air quality projections and further work is necessary to make this forecast. This is scheduled for Phase II of this program.

While several areas of improvement needed in the Environmental Impact Statement air pollution analysis have been noted above, this is not an attempt to criticize the St. Louis Metropolitan Area Airport Authority's efforts. Many other impact statements carry the same deficiencies, and the entire impact statement procedure has come under criticism. Complaints have been voiced that the statements have become a weapon used by special interest groups to achieve their own goals. Project leaders are accused of using them as justification documents, while environmental groups have been accused of using them as a legal weapon to stall much-needed programs. Clearly, some revision of current procedures seems necessary. The first step should probably be to make the statements what they were originally intended to be, that is, an assessment of the impact on environmental quality of a project from an objective and factual point of view, and a presentation of the strategies that will be employed to maintain an acceptable environmental quality. The methodology to be developed in this report is designed to provide the tools to make such assessments and such presentations.

3.0 PREPARATION OF AIRPORT EMISSION FORECASTS

The purpose of this section is to outline the procedure for estimating air pollutant emissions from the airport proper. A substantial amount of information relevant to the particular airport under study is needed. This information is divided into two categories: airport activity data and air pollutant emission factors for airport activities. The application of the emission factors to the activity levels results in an estimate of emissions for the given airport.

3.1 Airport Activity Levels

The purpose of this section is to describe the data necessary to represent airport activity and to outline methods of gathering the information. The new St. Louis airport is used to illustrate the procedure.

The collection of sufficient data to represent the activity level of an airport can be a large or a small task depending on one's definition of "sufficient data." In general, the philosophy recommended in this report is to collect as much detailed and airport-specific information as time and resource constraints allow. Additional required information can then be extrapolated from the wealth of data published for other airports. In some cases, this may result in a detailed description of one phase of airport activity and only a coarse approximation of another phase. This does not reduce the credibility of the output so long as the extent of the approximations are kept in mind.

For airports already in operation, the collection of first-hand data means the setting up of a program of visits to the airport to make direct observations. This is the most accurate as well as time- and resource-consuming procedure. A detailed description of this procedure as applied to Chicago's O'Hare International Airport has already been published.[10]

For airports only in the planning stage, reliance must be placed upon the engineering studies which are drawn up as part of the airport need justification. These studies will, in general, contain sufficient information to enable a reasonable emission estimate to be made. The engineering studies made for the proposed new St. Louis airport have been discussed in Section 2.0.

Figure 3.1 is a schematic description of the various activities of a commercial air carrier airport which are likely to result in significant air pollutant emissions. The actual emission sources are indicated by circular figures on the diagram. Inspection of the figure indicates that each activity can be classified as an independently variable activity or a dependently variable activity. The primary independently variable activities (i.e., the boxes having no input arrows) are the passenger demand and the air cargo demand. All other activity levels can presumably be determined from this information. In practice, however, the aircraft activity level is a semi-independently variable activity. Though the activity is directly proportional to passenger and cargo demand, it is also dependent on external influences such as aircraft technology. The introduction of jumbo jets, wide-body jets, STOL aircraft, and SST's can change the activity level and mix even though the passenger and cargo demand remains constant.

The dependently variable activities are the ground service vehicle activity and mix, the fuel storage and handling system, the engine test and maintenance facility, the building heating and air conditioning plant, and the access traffic activity and mix.

Each of these activities will be discussed in the following sections, and methods will be outlined for estimating each activity level.

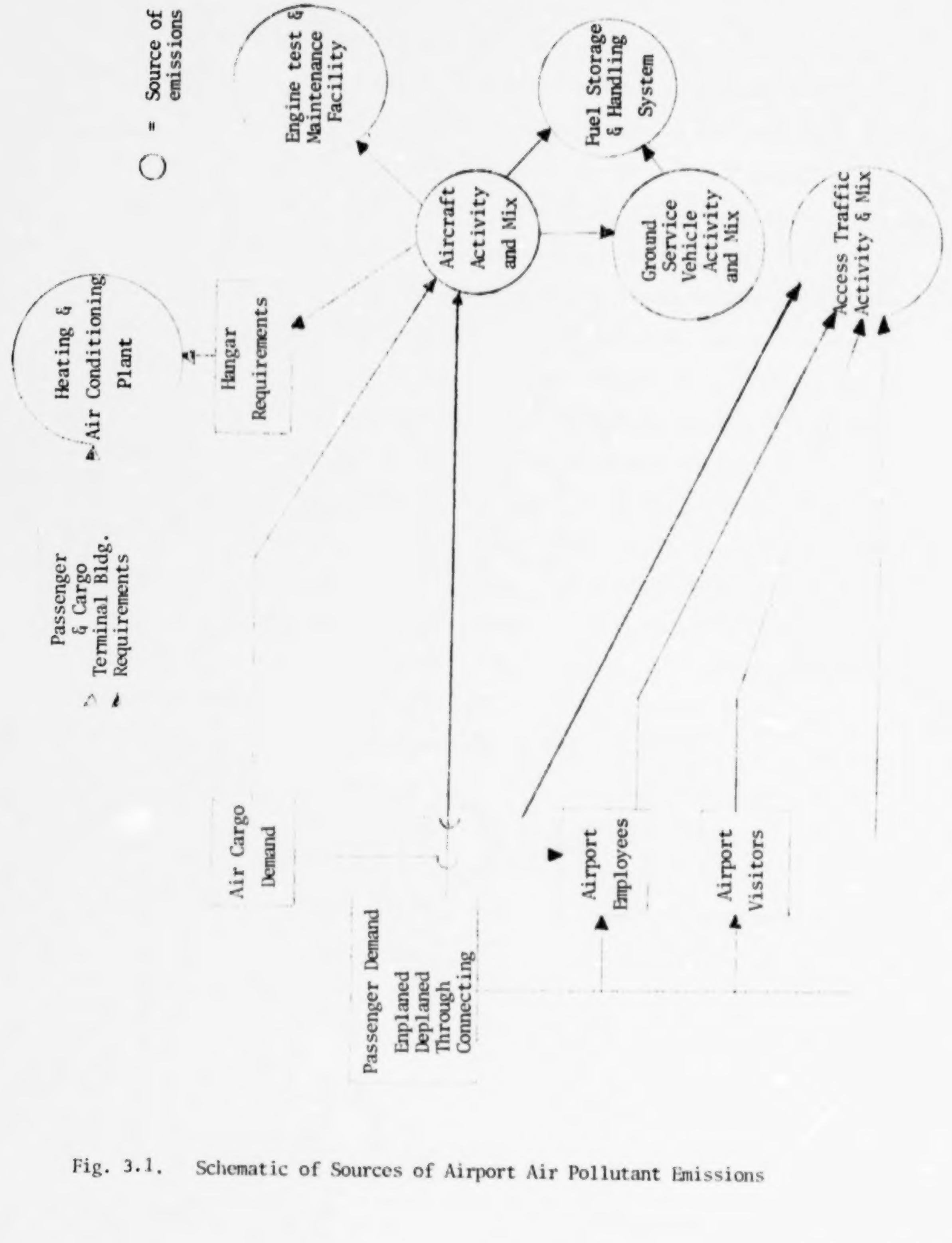

○ = Source of emissions
Engine test & Maintenance Facility
Fuel Storage & Handling System
Aircraft Activity and Mix
Ground Service Vehicle Activity and Mix
Access Traffic Activity & Mix
Heating & Air Conditioning Plant
Hangar Requirements
Passenger & Cargo Terminal Bldg. Requirements
Air Cargo Demand
Passenger Demand
Enplaned
Deplaned
Through
Connecting
Airport Employees
Airport Visitors

Fig. 3.1. Schematic of Sources of Airport Air Pollutant Emissions

3.1.1 Passenger Demand

The air carrier passenger demand level is the main motivating factor behind an air carrier airport. Without the desire for air travel, there would be no need for an airport. The passenger demand level is measured by the number of air travelers boarding aircraft at the airport under study. This number is termed the enplaning passenger rate. The enplaning passenger rate includes originating passengers and connecting passengers (persons arriving at the airport aboard one aircraft and departing aboard another). The deplaning passenger rate which includes terminating and connecting passengers is approximately equal to the enplaning rate. The through passenger rate includes persons arriving and departing the airport aboard the same aircraft. The enplaning passenger rate is a function of the region surrounding the airport. The factors which most influence this demand for air travel are employment in trade industries, regional population and family income, in that order.[11]

For an airport already in operation, the enplaning passenger rate is readily available from statistics kept by the airlines.

Several techniques are available for estimating the enplaning passenger rate for a proposed airport. A sophisticated regional socio-economic model can be designed which evaluates the above-mentioned factors along with several secondary factors and determines the expected number of enplanements. A simpler method is to forecast the enplanement growth rate based on past information and trends. This technique requires only a simple growth rate be applied to current enplanements. A combination of the techniques would forecast a growth of the national air travel demand and prorate the study airport's share of that growth based on the regional socio-economic parameters.

Of the studies done for the proposed new St. Louis airport, the NADC study,[3] the McDonnell study,[4] and the ATA/TWA study,[6] utilize the simpler technique of applying growth factors to the current enplanement rate. The FAA[5] and Speas[2] studies utilize the combination approach. The growth rates utilized in the NADC and McDonnell studies and the resulting growth rates of the Speas study are given on Table 3.1.

For the purposes of this report, it will be assumed that the passenger enplanement rate is a given value. A detailed analysis of the above-mentioned forecasting techniques is considered to be beyond the scope of this analysis.

The enplaning passenger rate for the proposed new St. Louis airport, as determined in the above-mentioned studies and as summarized in the Environmental Impact Statement[1] is given in Table 3.2.

Passenger activity characteristics as they are related to the access traffic activity are discussed in Section 3.1.8.

3.1.2 Air Cargo Demand

The air cargo demand for an operating airport is readily available from airport statistics. Generally this data can be obtained from the same sources as the air passenger data.

The air cargo forecast for a proposed airport is generally obtained by applying a growth factor to the current air cargo activity. The air cargo is divided among freight, express, and mail. As with the passenger forecasts, distinction must be made between originating air cargo, transfer air cargo (cargo unloaded off one airplane and loaded onto another), and terminating air cargo.

Table 3.1

Passenger Enplanement Growth Rates St. Louis Airport

Average Annual Change Over Previous Forecast Year
(Percent)

	NADC	McDonnell	Speas
1970	-	10.1	NA
1971	1.0	10.1	NA
1972	9.5	10.1	NA
1973	10.0	10.1	NA
1974	10.5	10.1	NA
1975	10.5	10.1	NA
1976-1980	10.0	10.1	8.9 (1980)
1981-1985	9.2	10.1	NA
1986-1990	8.5	10.1	7.9 (1990)
1991-1995	7.6	10.1	NA
1996-2000	6.4	10.1	5.4 (2000)

NA - Not Available

Table 3.2

Annual Air Carrier Passenger Enplanements

St. Louis Airport

(Millions of Passengers)

Source	1970	1975	1980	1985	1990	1995	2000
ATA/TWA	3.4	5.9	9.7	-	-	-	-
McDonnell	3.1	5.5	8.7	13.7	21.6	-	-
FAA (Fiscal Year)	3.1	5.0	8.2	13.6	-	-	-
NADC	2.8	4.2	6.8	10.5	15.8	22.7	31.0
Speas	3.4	5.3	8.1	12.0	17.5	23.6	30.7

From Ref. 1, Fig. 1-1

For the proposed new St. Louis airport, the air cargo forecasts are given in Table 3.3. Note should be taken that the NADC forecast is for enplaned air cargo which includes transfer cargo. The Speas forecast is for originating cargo only.

For the purposes of this study, it will be assumed that the air cargo forecast is known along with the enplaning passenger rate.

3.1.3 Aircraft Activity and Mix

Aircraft activity and mix is perhaps the single most important piece of accurate information needed to estimate air pollutant emissions from airports. The activity level is measured by the number of aircraft movements or operations, or by the number of aircraft landing-takeoff (LTO) cycles. An aircraft movement is either a landing or a takeoff. An LTO cycle consists of two movements and hence, has an activity level that is one-half the number of movements. The mix is measured by the fraction that each aircraft type makes up of the total number of movements.

For operational airports, the annual and peak hour aircraft activity and mix can be obtained from the records which are required to be kept by the Federal Aviation Administration. The published airline schedules are another good source of data, although using schedules alone will cause the investigator to miss the non-scheduled, charter, and general aviation activity which can make up a significant fraction of the total activity at a commercial air carrier airport.

For a proposed airport the annual aircraft activity can be derived from the passenger activity. This calculation, however, requires the estimation of two additional parameters: average aircraft seating capacity and aircraft load factors. The estimation of these parameters, in turn, requires the estimation of annual average aircraft mix at the study airport.

Table 3.3

Air Cargo Forecast

St. Louis Airport

	NADC Study (Enplaning Tons)	Annual Change (%)	Speas Study (Originating Tons)	Annual Change (%)
1970	—	—	43,547	14
1971	58,000	15	—	—
1972	67,850	17	—	—
1973	79,950	18	—	—
1974	93,250	17	—	—
1975	108,400	16	83,014	14
1980	211,350	14	159,836	12
1985	409,450	13	281,687	12
1990	746,950	10	496,427	10
1995	1,223,500	10	799,500	10
2000	2,008,500	10	1,287,604	8

As mentioned previously annual average aircraft mix is as much dependent on the external influences of developing technology as on the characteristics of the air passenger demand. The introduction of jumbo jets (B-747) and air buses (DC-10, L1011) drastically changes the available seat capacity and hence offers the airline schedulers many alternatives for meeting the passenger demand. If the diurnal pattern of demand for air travel reaches extreme values at certain hours of the day then the trend will be toward utilizing the high capacity airplanes during those hours and substituting lower capacity aircraft during the slack hours. If the pattern is more evenly distributed then the trend will be toward medium capacity aircraft throughout the day. Likewise, the passenger trip length will influence the choice of short-haul or long-range equipment.

This interaction of the technological developments with the characteristics of the passenger demand leads to an exceedingly difficult task of estimating aircraft mix. There are a multitude of alternative equipment combinations which will satisfy the demand. The problem, in essence, does not have a unique solution. Estimates of aircraft mix, therefore, should be made by those thoroughly familiar with the characteristics of the passenger demand and with probable technological advances. The ability to make a reasonably educated guess is also of great value.

Once the mix estimates are made, the generation of annual aircraft movements from air passenger enplanements then becomes a straightforward process. Additional perturbations in the scheme can be introduced to account for specific situations relevant to the study airport.

Estimates of peak hour aircraft activity are included as part of the engineering studies of a proposed airport because they are strong indicators of airport capacity. The peak hour activity is important to the emission calculation in its relationship to the overall diurnal pattern of weather in the airport vicinity. Should maximum activity (maximum emissions) occur at a time when the ventilating characteristics of the atmosphere are at a minimum the resulting air quality could be substantially degraded. Experience shows that fortunately this is not generally the case but this will be discussed in more detail in Section 5.0.

The peak hour aircraft activity is generally taken as some fraction of the annual activity. As with the annual average aircraft mix the peak hour mix estimate is a function of the experience and predicative capability of the forecaster.

The studies done for the proposed new St. Louis airport will be used to illustrate the aircraft activity forecasting technique. The studies do not all give complete results for the necessary parameters, annual and peak hour activity and annual and peak hour mix, but enough information can be extracted to perform the emission calculation if certain assumptions are used to fill in the gaps.

NADC Study[3]

To make the annual activity forecast NADC first estimates,for the various aircraft expected to be in service during the forecast period,the average seating capacity per aircraft type, the load factor for each aircraft, and the deplanement/enplanement factor for each aircraft (i.e. the fraction of available seats that are assigned to passengers destined to or from St. Louis; this is a compensating factor for through passengers). This enables a computation of the average number of passengers enplaning or deplaning per aircraft movement for each aircraft type. A separate estimate is made for the fraction of annual movements that will be made by each of the aircraft types. This information is then used to weight the passengers per aircraft movement for each aircraft type and arrive at an overall average passengers per aircraft movement figure. The data used by NADC is given on Table 3.4.

In proceeding to calculate annual air carrier movements NADC uses the total enplaning plus deplaning passenger rate, referred to as the air passenger movement rate. This is taken as simply twice the enplaning passenger rate as described in Section 3.1.1. NADC reduces the air passenger movement rate by 1% to account for passengers moved by air taxi. The previously calculated value of average passengers per aircraft movement is then applied to this reduced value of passenger movements to get the number of scheduled air carrier aircraft movements. This number is increased by 7.5% to account for non-scheduled air carrier movements. (The value 7.5% is typical of St. Louis from historical data.) The scheduled plus non-scheduled movements give the total air carrier movements for the year.

Air taxi movements are determined by dividing the number of air taxi passengers (i.e. the 1% of passenger movements previously deducted by an average aircraft size varying from 20-30 passengers in the time span 1980-2000 and by a 50% load factor.

General aviation movements are assumed to be 5% of the total aircraft activity.

Table 3.4 Aircraft Mix, Seat Capacity, and Load Factor Estimates

NADC Study - St. Louis Airport*

Aircraft Type	Pctage. of Total Annual Scheduled A/C Movements			Avg. No. of Seats per A/C Type			Load Factor			Deplanement Enplanement Factor			Passengers Per Aircraft Movement		
	1980	1990	2000	1980	1990	2000	1980	1990	2000	980	1990	20'	1980	1990	2000
Jumbo Jets (B-747)	5	10	20	375	450	525	.45	.55	.60	.80	.75		135	186	236
Air Buses (DC-10/ L-1011)	30	50	60	250	300	350	.48	.60	.60	.80	.75	.75	96	135	158
4-Engine Conventional Jets (B-707/DC-8)	10	5	--	140	140	--	.50	.55	--	.80	.75	--	56	58	--
2 and 3 Engine Conventional Jets (B-727/ DC-9)	52	--	--	110	--	--	.50	--	--	.80	--	--	44	--	--
STOL/VTOL	--	30	20	--	110	110	--	.55	.65	--	.90	.90	--	54	64
Small 2-Engine Conventional Jets (F-28)	3	5	--	70	70	--	.50	.50	--	.90	.90	--	32	32	--
	Avg. No. of Seats per Aircraft			167	238	337				Avg. No. of Passengers per Air Carrier Aircraft Movement			65	107	155

*From Ref. 3, Table 4-8.

The sum of the air carrier movements, the air taxi movements and the general aviation movements yields the total number of annual aircraft movements. The calculation procedure is shown on Table 3.5.

Annual average aircraft mix can be determined by adding the air taxi and general aviation forecasts to the air carrier forecasts and recomputing the percentages given on Table 3.4.

The peak hour activity is determined by taking appropriate fractions of the annual activity. NADC assumes the peak month air carrier operations to be 9% of the total annual operations, peak day to be 3.7% of the peak month, and peak hour to be 7% of the peak day. Peak hour movements of air taxi and general aviation aircraft were obtained by distributing the annual activity equally over 365 days and over an assumed 12-hour operational day, and adding these numbers to the air carrier activity.

The peak hour mix is not given in the NADC forecast.

A summary of the NADC forecasts will be presented in Table 3.10.

McDonnell Study[4]

The McDonnell Study proceeds in essentially the same manner as the NADC Study. That is, estimates of aircraft load factors and annual average available seats are made and applied to the enplaning passenger figure to arrive at annual aircraft movements. The aircraft mix used to derive the annual average available seats is not given. No estimate is made for general aviation activity, and the perturbations of non-scheduled air carrier activity and air taxi activity are not included.

The data used by McDonnell for the annual activity calculations is given on Table 3.6. The calculation procedure is illustrated on Table 3.7.

Table 3.5

Calculation Procedure for Annual Aircraft Movements

NADC Study

(1)
$$\frac{\begin{bmatrix}\text{Total Air Passenger}\\ \text{Movements}\end{bmatrix} - \begin{bmatrix}\text{Air Taxi}\\ \text{Passenger}\\ \text{Movements}\end{bmatrix}}{\begin{bmatrix}\text{Avg. No. of Passengers}\\ \text{per A/C Aircraft Movement}\end{bmatrix}} = \begin{bmatrix}\text{Scheduled Air Carrier}\\ \text{Aircraft Movements}\end{bmatrix}$$

where
$$\begin{bmatrix}\text{Air Taxi}\\ \text{Passenger}\\ \text{Movements}\end{bmatrix} = .01 \begin{bmatrix}\text{Total Air}\\ \text{Passenger}\\ \text{Movements}\end{bmatrix}$$

(2)
$$\begin{bmatrix}\text{Scheduled}\\ \text{Air Carrier}\\ \text{Movements}\end{bmatrix} \times .075 = \begin{bmatrix}\text{Non-Scheduled}\\ \text{A/C Aircraft}\\ \text{Movements}\end{bmatrix}$$

(3)
$$\frac{\begin{bmatrix}\text{Air Taxi}\\ \text{Passenger}\\ \text{Movements}\end{bmatrix}}{\begin{bmatrix}\text{Avg. No. of Passengers per}\\ \text{Air Taxi Aircraft Movement}\end{bmatrix}} = \begin{bmatrix}\text{Air Taxi}\\ \text{Aircraft Movements}\end{bmatrix}$$

(4)
$$\frac{\begin{bmatrix}\text{Scheduled Air}\\ \text{Carrier Movements}\end{bmatrix} + \begin{bmatrix}\text{Non-Scheduled}\\ \text{A/C Movements}\end{bmatrix} + \begin{bmatrix}\text{Air Taxi}\\ \text{Movements}\end{bmatrix}}{19} = \begin{bmatrix}\text{General Aviation}\\ \text{Aircraft Movements}\end{bmatrix}$$

(5)
$$\begin{bmatrix}\text{Scheduled Air}\\ \text{Carrier Movements}\end{bmatrix} + \begin{bmatrix}\text{Non-Scheduled}\\ \text{A/C Movements}\end{bmatrix} + \begin{bmatrix}\text{Air Taxi}\\ \text{Movements}\end{bmatrix} + \begin{bmatrix}\text{General Aviation}\\ \text{Movements}\end{bmatrix}$$
$$= \begin{bmatrix}\text{Total Annual}\\ \text{Aircraft}\\ \text{Movements}\end{bmatrix}$$

Table 3.6

Aircraft Seat Capacity and Load Factor Estimates

McDonnell Study

	Enplaning* Load Factor (%)	Average Number of Seats per Aircraft
1970	39.3	92
1975	44	117
1980	49	134
1985	50	166
1990	50	211

* For originating and connecting passengers only. Does not include through passengers.

Table 3.7

Calculation Procedure for Annual Aircraft Movements

McDonnell Study

$$(1) \qquad \frac{\left[\text{Enplaned Air Carrier Passengers}\right]}{\left[\text{Enplaning Load Factor}\right]} = \left[\text{Required No. of Departing Seats}\right]$$

$$(2) \qquad \frac{\left[\text{Required No. of Departing Seats}\right]}{\left[\text{Avg. No. of Seats per Aircraft}\right]} = \left[\text{No. of Air Carrier Aircraft Takeoffs}\right]$$

$$(3) \qquad \left[\text{No. of Air Carrier Aircraft Takeoffs}\right] \times 2 = \left[\text{Total Annual Air Carrier Movements}\right]$$

The peak hour aircraft activity as forecast by McDonnell does not maintain a percentage ratio to annual movements. The Environmental Impact Statement[1] makes special note of this factor in its summary of the different studies.

Peak hour mix is given and will be presented on Table 3.10, along with a summary of the McDonnell forecast.

Speas Study[2]

The Speas Study was not available for review but the Environmental Impact Statement contains sufficient information to enable a description of the Speas procedure to be made. The procedure is based on a load factor and a seat capacity estimate for the annual activity forecast, as with the other studies. Annual aircraft mix is not available. The Speas data for the annual calculations is given on Table 3.8 and a description of the calculation procedure is on Table 3.9.

Peak hour movements are taken as .0235% of the annual activity. This is approximately the same as the NADC figure.

Peak hour mix estimates are made and will be summarized on Table 3.10 with the rest of the Speas forecast.

Other Studies

The FAA[5] and the ATA/TWA[6] studies were not available, and insufficient information was presented in the Impact Statement[1] to enable an evaluation of their procedures to be made. A summary of the forecast results, however, will be presented on Table 3.10.

The results of the above forecasting techniques for St. Louis annual and peak hour aircraft movements and annual and peak hour mix are given on Table 3.10. The procedures described above used to make these estimates are designed to be illustrative and not comprehensive.

Table 3.8

Aircraft Seat Capacity and Load Factor Estimates

Speas Study

	Enplaning* Load Factor (%)	Avg. No. of Seats per Aircraft
1980	43	153
1990	50	202
2000	50	300

* For originating and connecting passengers only. Does not include through passengers.

Table 3.9

Calculation Procedure for Annual Aircraft Movements

Speas Study

(1) $$\begin{bmatrix}\text{Avg. No. of Seats}\\ \text{per Aircraft}\end{bmatrix} \times \begin{bmatrix}\text{Enplaning}\\ \text{Load Factor}\end{bmatrix} = \begin{bmatrix}\text{Enplaned Passengers per}\\ \text{A/C Aircraft Takeoff}\end{bmatrix}$$

(2) $$\frac{\begin{bmatrix}\text{Enplaned Air Carrier}\\ \text{Passengers}\end{bmatrix}}{\begin{bmatrix}\text{Enplaned Passengers per}\\ \text{A/C Aircraft Takeoff}\end{bmatrix}} = \begin{bmatrix}\text{Scheduled}\\ \text{A/C Takeoffs}\end{bmatrix}$$

(3) $$\begin{bmatrix}\text{Scheduled}\\ \text{A/C Takeoffs}\end{bmatrix} \times .075 = \begin{bmatrix}\text{Non-Scheduled}\\ \text{A/C Takeoffs}\end{bmatrix}$$

(4) $$\left\{\begin{bmatrix}\text{Scheduled}\\ \text{A/C Takeoffs}\end{bmatrix} + \begin{bmatrix}\text{Non-Scheduled}\\ \text{A/C Takeoffs}\end{bmatrix}\right\} \times 0.15 = \begin{bmatrix}\text{Air Cargo and}\\ \text{General Aviation}\\ \text{Takeoffs}\end{bmatrix}$$

(5) $$\left\{\begin{bmatrix}\text{Scheduled}\\ \text{A/C Takeoffs}\end{bmatrix} + \begin{bmatrix}\text{Non-Scheduled}\\ \text{A/C Takeoffs}\end{bmatrix} + \begin{bmatrix}\text{Air Cargo and}\\ \text{General Aviation}\\ \text{Takeoffs}\end{bmatrix}\right\} \times 2$$

$$= \begin{bmatrix}\text{Total Annual}\\ \text{Aircraft}\\ \text{Movements}\end{bmatrix}$$

Table 3.10
Summary of Aircraft Activity and Mix Forecasts
St. Louis Airport

NADC Annual Forecasts/ Peak Hour Forecasts	1970	1975	1980	1985	1990	1995	2000
Total Aircraft Movements*			247000/58	303000/71	357000/83	430000/100	492000/114
Aircraft Mix (%)**							
Jumbo Jets (B-747)			4.5	6.2	8.8	12.2	17.3
Air Buses (DC-10/L1011)			26.9	36.5	43.9	48.9	52.0
4-Engine Conventional Jets (B-707/DC-8)			8.9	6.7	4.4	2.2	0.
2- & 3-Engine Conven'l Jets (B-727/DC-9)			46.5	23.1	0.	0.	0.
STOL/VTOL			0.	12.9	26.4	21.8	17.3
Small 2-Engine Conven'l Jets (F-28)			2.7	3.5	4.4	2.2	0.
Air Taxi			5.5	6.1	7.1	7.7	8.4
General Aviation			5.0	5.0	5.0	5.0	5.0

*Aircraft Movement forecasts include air carrier (scheduled and non-scheduled), air taxi, and limited general aviation activity.

**Aircraft Mix estimates are for annual operations only. Peak Hour Mix estimate is not available.

Table 3.10 (Contd.)

Summary of Aircraft Activity and Mix Forecasts

St. Louis Airport

	1970	1975	1980	1985	1990	1995	2000
McDonnell Annual Forecasts/ Peak Hour Forecasts							
Total Aircraft Movements*	174000/46	212000/50	265000/59	330000/78	410000/102		
Aircraft Mix (%)**							
Category 1 (747)	0.	2.0	5.1	9.0	15.7		
Category 2 (DC-10/ L1011/DC-8-63)	0.	18.0	30.5	41.0	45.1		
Category 3 (727/ 707/DC-8)	71.7	48.0	40.6	30.8	23.5		
Category 4 (DC-9/ FH227)	13.0	16.0	8.5	5.1	2.0		
Category 5 (General Aviation)	15.3	16.0	15.3	14.1	12.8		

*Annual Forecasts are for air carrier operations only. Peak Hour Forecasts are for air carrier, air cargo and limited general aviation aircraft movements.

**Aircraft Mix estimates are for peak hour operations only. Annual mix estimate not available.

Table 3.10 (Contd)

Summary of Aircraft Activity and Mix Forecasts

St. Louis Airport

	1970	1975	1980	1985	1990	1995	2000
Speas Annual Forecasts/ Peak Hour Forecasts							
Total Aircraft Movements*		272000/64	304000/71	361000/85	428000/101	475000/111	506000/119
Aircraft Mix (%)**							
Category AA (B-747/DC-10/L1011/DC-8-60)		15.6	29.6	43.5	51.5	60.4	67.2
Category A (B-707/DC-8/B-720/CV-880)		6.3	5.6	0.	0.	0.	0.
Category B (B-727/DC-9/B-737/BAC/CV)		57.7	52.2	43.5	35.6	27.0	20.2
Category C (F-27/Gulfstream/Lear Jet/ Falcon/King Air/DC-3)		11.0	5.6	7.1	7.9	8.1	8.4
Category D & E (Cessna 310, 320, 411, 150-210/Piper Apache, Aztec, Cherokee, Comanchee/ Beech Queen Air)		9.4	7.0	5.9	5.0	4.5	4.2

*Aircraft Movement forecasts include air carrier (scheduled and non-scheduled), air cargo, and limited general aviation activity.

**Aircraft Mix estimates are for peak hour operatons only. Annual mix estimate not available.

Table 3.10 (Contd.)

Summary of Aircraft Activity and Mix Forecasts

St. Louis Airport

	1970	1975	1980	1985	1990	1995	2000
FAA Annual (FY) Forecasts A/C Aircraft Movements †Extrapolated	192000	209000	248000	311000†			
ATA/TWA Annual Forecasts/ Peak Hour Forecasts							
A/C Aircraft Movements	183000/42	242000/52	319000/67				
Total Aircraft Movements*	412000/81	524000/107	670000/147				

*Total Aircraft Movement forecasts include air carrier, air cargo, and unlimited general aviation and military activity.

It will be noted that the air cargo forecast does not enter as a determining factor. It is included only in a cursory way in the Speas forecast (see Table 3.9). The reason for this is that based on the projections for air cargo given in Section 3.1.2 the aircraft which will meet the passenger demand will also meet the cargo demand.

All of the studies mentioned above indicate that, barring the introduction in the St. Louis area of a large bulk commodity requiring all-cargo aircraft, the forecast cargo tonnage can be handled by the cargo holds of the passenger aircraft.

The information presented on Table 3.10 is the type of data on aircraft activity and mix that is needed to estimate aircraft emissions. In the cases where the data is not complete it is possible to utilize the given information to calculate emissions. For example, the McDonnell and Speas forecasts do not give an annual aircraft mix. The peak hour mix, although probably different from the annual mix will be used instead. Since the change in mix is much more dramatic from forecast year to forecast year than it would be from peak hour to annual average in any given year this approximation is probably not a bad one to make.

This type of filling in of data gaps is what is necessary to make an emission estimate with a reasonable amount of time and resources expended.

Diurnal Activity

The diurnal pattern of aircraft activity at an airport is an important piece of information for the reasons alluded to previously in the discussion of peak hour forecasting. Should maximum activity occur at the same time of day as minimum atmospheric ventilation the air quality could be seriously degraded. Conversely, should maximum activity occur during maximum ventilation the air quality impact would be minimized.

The diurnal activity is measured by the total number of aircraft movements occuring during each hour of the day. The Environmental Impact Statement presents a diurnal demand pattern for Lambert Field based upon the Speas study. Speas is reported to have used historical air traffic data from FAA Forms 7230-1, observations of traffic taken on field survey, discussions with FAA personnel, and experience at other airports to generate this pattern. The diurnal variation is given on Table 3.11.

The NADC report also presents a diurnal activity pattern but this is for scheduled air carrier activity only. Since non-scheduled air carrier, air taxi, and general aviation movements make up a significant part of the activity at St. Louis the NADC pattern will not be used.

It will be assumed that the diurnal pattern will not change over the forecast period to the year 2000.

3.1.4 Ground Service Vehicle Activity and Mix

The ground service vehicles are those pieces of motorized equipment which operate in the gate areas to load and unload aircraft and otherwise prepare the airplane for its next departure. The activity level and mix of equipment is dependent on the type of aircraft being serviced. Different airlines also choose different pieces of equipment to service the same type of airplane.

The primary variable which will be used to estimate emissions from ground service vehicles is the amount of time spent by each vehicle type servicing a particular aircraft. Total service times as a function of

Table 3.11

Diurnal Aircraft Activity

St. Louis Airport

Hour	Percent of Daily Aircraft Movements Occurring During the Hour
1	0.97
2	0.97
3	0.45
4	0.45
5	0.52
6	0.52
7	2.60
8	2.60
9	6.24
10	6.24
11	6.76
12	6.76
13	6.91
14	6.91
15	6.46
16	6.46
17	7.43
18	7.43
19	5.87
20	5.87
21	4.08
22	4.08
23	1.71
24	1.71
	100.00

aircraft type are given in Table 3.12 for the various kinds of ground support vehicles. These data were obtained from questionnaires completed by airline representatives, personal interviews with airline employees and observations of ramp activities at O'Hare International Airport in Chicago.[12] The data are averaged values of service times for the different airlines participating in the survey at O'Hare. In addition to the vehicles listed in Table 3.12, there are a few others not listed which are not routinely used to service aircraft in the ramp area and hence are not incorporated into the activity estimate. These include deicers, glycol trucks, lift trucks, and others. Operation time of these vehicles is generally small compared to most of the others listed in the table.

The ground service vehicle operating times are computed on a diurnal basis by multiplying one-half the total number of arrivals and departures of each aircraft type in an hour by the service time of each vehicle type. This method accounts for the fact that in any given hour there may be more arrivals than departures or vice-versa, but this discrepancy cancels out on a daily basis.

Table 3.13 gives the projected time of ground service vehicle operations based upon the Speas aircraft activity and mix forecasts of Table 3.10 and the service times on Table 3.12.

Table 3.12

Service Times of Aircraft Ground Service Vehicles

Vehicle \ Aircraft	B-747	DC-10	B-707	DC-8	B-727	DC-9	B-737	C-880	F-227	C-580
	Time in Vehicle-Minutes									
1. Tractor	155	148	66	98	66	48	85	40	55	50
2. Belt Loader	48	40	37	30	28	15	30	40	0	25
3. Container Loader	92	80	12	0	6	0	0	0	0	0
4. Cabin Service	24	25	12	15	12	0	15	0	0	0
5. Lavatory Truck	24	18	15	18	15	15	15	20	10	10
6. Water Truck	12	10	0	0	0	10	0	0	10	10
7. Food Truck	55	20	20	30	17	17	20	20	10	10
8. Fuel Truck	50	45	37	40	20	15	15	20	10	20
9. Tow Tractor	10	10	10	5	10	5	5	15	5	5
10. Conditioner[a]	0	0	30	30	0	0	0	0	0	0
11. Airstart[b]										
Transporting Engine	3	0	10	5	0	0	0	15	0	0
Diesel Power Unit	2	0	8	4	0	0	0	11	0	0
12. Ground Power Unit[c]										
Transporting Engine	0	0	9	0	0	0	0	35	0	0
Gasoline Power Unit	0	0	4	0	0	0	0	15	0	0
Diesel Power Unit	0	0	4	0	0	0	0	15	0	0
13. Transporter	19	0	10	0	3	0	0	0	0	0
14. Auxillary Power Unit[d]	Yes	Yes	No	No	Yes	Yes	Yes	No	No	No

Table 3.12 (Contd.)

Service Times of Aircraft Ground Service Vehicles

Footnotes:

a. Normally used only in very hot or cold weather.

b. The airstart vehicle consists of a diesel generator mounted on the back of a truck. It is assumed that the truck engine runs continuously for the entire service time and the diesel generator runs for 75% of the time.

c. The ground power unit consists of a generator mounted on the back of a truck. It is assumed that the truck engine and the generator run continuously. About half of the generator units in service are diesel and the other half are gasoline engine. Hence, the generator service time is divided equally between a gasoline and diesel engine.

d. If an aircraft has an auxillary power unit, it normally runs for the entire gate occupancy time. Its emissions are included in the aircraft calculations.

Data from Ref. 12

Table 3.13

Total Daily Ground Service Vehicle Operating Time
Speas Study Aircraft Activity - St. Louis Airport

Year / Vehicle	Time in Vehicle-Hours					
	1975	1980	1985	1990	1995	2000
1. Tractor	422	568	779	1010	1210	1365
2. Belt Loader	135	182	236	299	352	393
3. Container Loader	101	190	320	447	574	676
4. Cabin Service	51	77	110	146	179	205
5. Lavatory Truck	88	108	135	167	191	208
6. Water Truck	35	44	63	80	96	106
7. Food Truck	116	153	202	259	306	342
8. Fuel Truck	131	180	239	310	372	420
9. Tow Tractor	44	53	66	81	92	100
10. Conditioner	11	13	0	0	0	0
11. Airstart						
Transportation Engine	5	7	6	8	10	12
Diesel Power Unit	4	5	5	6	8	9
12. Ground Power Unit						
Transportation Engine	2	2	0	0	0	0
Gasoline Power Unit	1	1	0	0	0	0
Diesel Power Unit	1	1	0	0	0	0
13. Transporter	19	28	40	54	68	78

3.1.5 Fuel Handling and Storage System

The operation of a major air carrier airport requires the storage and handling of an extremely large quantity of fuel for both aircraft and ground service vehicles. Fuel consumption at Chicago's O'Hare is on the order of 75 million gallons of jet fuel and 300,000 gallons of gasoline per month.[13] The handling of such large volumes of fuel leads to the loss of significant quantities through evaporation and spillage during transfer from tank to tank. These losses appear as air pollutant emissions and should be accounted for in the emission calculation. Since jet and ground service vehicle fuels are hydrocarbon compounds, the emissions resulting from evaporation and spillage are to be counted as part of the total airport hydrocarbon emission.

In order to compute the emissions from fuel storage and handling, an estimate must be made for the total amount of fuel that is to be handled on the airport site. For aircraft, it is not a trivial matter to estimate the fuel requirements. If one simply tabulates the fuel capacity of each aircraft type and attempts to calculate fuel requirements based on the number of aircraft operations, the resulting quantity will be a serious overestimate. This is true since aircraft rarely must take on a full load of fuel at any one destination. Fuel left in the tanks when the aircraft lands can be a sizeable fraction of the capacity. This is especially true for an airport such as St. Louis where a large number of flights are of short to medium-range distance. Instead of this direct computation, an indirect approach will be used. Based on O'Hare data[13], the average amount of fuel pumped per aircraft LTO is approximately 2700 gallons. Data from Los Angeles[14] shows approximately 3200 gallons per LTO. This higher value can be attributed to the fact that Los Angeles serves a larger number of long-range flights. Since St. Louis operations are mostly of short- to medium-range, the lower fuel requirements of O'Hare will be used. Table 3.14 gives the projected annual aircraft fuel requirements for each of the three forecasts. Even though this estimating procedure is crude, the resulting projections are probably of the right order of magnitude.

For ground service vehicles, the amount of fuel required can be estimated by utilizing the vehicle activity already presented in Section 3.1.4. Additional information on fuel consumption rates of these vehicles will be presented in Section 3.2.2, but the results of applying the activity estimates to the consumption rates is presented on Table 3.15 as fuel required for ground service vehicles.

This information on aircraft fuel requirements and ground service vehicle fuel requirements will enable an estimate of fuel handling and evaporative emissions to be made. The diurnal distribution of emission will be taken to be the same as the aircraft diurnal distribution of Table 3.11.

3.1.6. Engine Test and Maintenance Facility

The operation of a major turbine engine maintenance and overhaul facility at an airport involves the testing of aircraft engines to insure proper performance and structural integrity. A test consists of running the engine mounted either on a special test stand or on the airplane through a set of typical flight conditions while measurements of performance are made. If a substantial number of such tests are performed, the air pollutant emissions can be significant and should be accounted for in the emission calculation.

Table 3.14

Annual Aircraft Fuel Requirements*

St. Louis Airport

	Millions of Gallons					
Forecast	1975	1980	1985	1990	1995	2000
NADC	-	**333**	409	482	581	664
McDonnell	286	**358**	446	554	-	-
Speas	367	410	**487**	578	641	683

*Based on an average of 2700 gallons of fuel per LTO.

Table 3.15

Annual Ground Service Vehicle Fuel Requirements

St. Louis Airport

	Thousands of Gallons					
Forecast	1975	1980	1985	1990	1995	2000
NADC						
Gasoline	-	789	1085	1414	1832	2228
Diesel Fuel	-	13	14	14	14	13
McDonnell						
Gasoline	737	1084	1507	2029	-	-
Diesel Fuel	40	45	46	49	-	-
Speas						
Gasoline	697	964	1321	1723	2081	2358
Diesel Fuel	13	18	12	17	22	26

The operation of a major maintenance facility at an airport is strictly a function of the decision of the airlines as to its location. It is an activity which can be tied to aircraft activity only after an assumption has been made as to the extent of the maintenance operations which are to be located at the study airport. In general, it can be said that airlines prefer to locate major maintenance facilities at airports which serve a large number of originating and terminating flights. Airports which serve mainly as connection points do not, in general, become the preferred location for large-scale maintenance and overhaul operations. To illustrate, Los Angeles International Airport is reported[14] to have 42 turbine engine run-ups per day in the test facility; San Francisco International Airport is reported[15] to use 11,300 gallons of jet fuel per day in maintenance operations; in contrast, Chicago's O'Hare International Airport has only one or two engine run-ups per day[16]. The reason for these differences is that San Francisco and Los Angeles are both terminating/originating points, while Chicago is a connection point.

In attempting to estimate the number of engine tests, the Los Angeles data[14] will be taken as representative of a major maintenance facility. Los Angeles International has approximately 403,000 aircraft movements per year. The 42 engine tests per day thus leads to a ratio of about 38 engine run-ups per 1000 aircraft movements in a day. It should be emphasized that these are engine run-ups and not aircraft run-ups; only one engine is operating at a time.

In attempting to apply this ratio to the proposed new St. Louis airport, it should be recognized that St. Louis is not likely to become a major maintenance facility because much of its air traffic is connecting.

On the other hand, it probably will not have as small a maintenance facility operation as O'Hare because of the location of a major aircraft manufacturer, McDonnell-Douglas, in the area. Hence it appears reasonable to assume that something on the order of 20 engine run-ups per 1000 aircraft movements in a day will be an adequate representation of the St. Louis operation. Table 3.16 gives the annual number of maintenance tests projected for each of the aircraft activity forecasts based on this assumption.

The emissions are distributed evenly over the hours of the day shift (9:00 AM to 4:00 PM) for purposes of diurnal emission estimates.

3.1.7 Heating and Air Conditioning Plant

As shown in Fig. 3.1, the expected activity level of air passengers and air cargo requires the sizing of terminal buildings to handle the volume comfortably. Likewise, the aircraft require hangars for service and maintenance. These buildings are generally heated and air-conditioned from a central plant located on the airport site. The operation of this plant can be expected to produce some quantity of air pollutant emissions.

The Environmental Impact Statement[1] estimates the building requirements to be 2.1×10^6 sq ft for the passenger terminal and 0.22×10^6 sq ft for the cargo terminal. With these building sizes, it is possible to estimate the amount of fuel required for space heating. Following standard procedures[17], it can be estimated that this building space in the St. Louis area will require, on an annual average, 13,354 therms (10^5 Btu) per day to heat. Assuming that coal or oil will be the fuel most likely to be used because of their abundance in the area, this heating requirement can be translated into fuel requirements using standard methods.[17] Table 3.17 summarizes the projected fuel requirements.

The heating plant emissions will be distributed equally over the day for the purpose of estimating diurnal patterns.

Table 3.16

Annual Aircraft Engine Maintenance Tests

St. Louis Airport

Year	Number of Engine Run-ups per Year* NADC Forecast	McDonnell Forecast	Speas Forecast
1975	-	4380	5475
1980	5110	5475	6205
1985	6205	6570	7300
1990	7300	8030	8395
1995	8760	-	9490
2000	9855	-	10220

*Based on 20 run-ups per 1000 aircraft movements in a day.

Table 3.17

Annual Fuel Requirements of Heating Plant

St. Louis Airport

Building Floor Space* (ft^2)	Required Energy** (therms/day)	Annual Fuel Required Coal (tons)	Oil (gallons)
2.3×10^6	13354	22.3×10^3	3.5×10^6

*From Ref. 1

**From Ref. 17

3.1.8 Access Traffic

Airports are essentially transfer stations where people can switch from ground transportation to air transportation or vice-versa. Since this role as a modal transfer point is fundamental to airports, the planning for adequate ground access facilities is as important as the planning for aircraft facilities. Ground transportation is a significant source of air pollutant emissions and hence must be included in the estimate of total airport emissions.

Existing airports lend themselves well to ground transportation studies. There are generally a limited number of roads leading into an airport and most of these serve only as acess to some area of the airport proper such as the terminal, the cargo area, hangar facility, and the like. This makes for relatively easy monitoring of traffic flows which are generated by airport activities. Surveys of airport users can be conducted in a simple and accurate fashion; passengers can be interviewed while their flight is in the air since they are effectively a captive audience; employees can be surveyed at their work stations; visitors can be interviewed in their normal collection point in the terminal. The relative ease with which airport-generated trips can be segregated from other urban travel has led to a wealth of data on ground transportation collected at many airports.

For an airport in the planning stages the ground access is included as a principle criteria in initial site selection. The cost and time-of-travel are critical parameters which go into the evaluation of alternative sites. Hence, there is likely to be a good deal of information on ground access generated as part of the engineering studies. This combined with the results of studies at existing airports provides a reasonably good data set from which to estimate ground access vehicle activity and hence air pollutant emissions.

When attempting to estimate airport ground access air pollutant emissions the important items of information needed are the following:

- Number of vehicle trips
- Mix of vehicles
- Vehicle distance travelled
- Vehicle operational characteristics

The total volume of vehicle trips is the primary parameter. The distribution of trips among the various types of vehicles (autos, taxis, buses, rail, etc.) is a necessary resolution of the data since emissions vary greatly with vehicle type. The travel distance is needed since air pollutant emission factors are given in the form of emissions per vehicle mile of travel. The manner in which the vehicles are operated on the airport grounds (speed, hot or cold start) substantially affects the emission rate. The illustration of the generation of this information for the proposed new St. Louis airport will make use of the data in the engineering studies and the information available from other airports.

As shown in Fig. 3.1, the driving functions behind the access traffic activity are the number of person trips generated by the airport. Because of their marked differences in ground travel patterns the people accessing the airport are divided into three groups: passengers, visitors, and employees. The visitor group is further subdivided into air passenger-related visitors and casual visitors.

Passengers

The passenger group includes both originating and terminating passengers as defined in Section 3.1.1. Both groups must make use of ground transportation to arrive or depart the airport. Through and connecting passengers by definition do not leave the airport, and hence make no demands on the ground transport system. There is a possibility, depending on the layout of the terminal, that connecting passengers would need some form of transport from one flight to another. This contingency will not be included in this study because of its non-universal character.

The Environmental Impact Statement[1] presents data from a passenger survey taken at Lambert Field in September, 1969. This indicated that during the survey period, 25.4% of the passengers were originating, 25.8% were terminating, 30.0% were connecting, and 18.8% were through. Assuming that over the forecast period, the originating and terminating passengers are equal in number, it can then be said that 46% of the enplaning passengers are originating in St. Louis. The remaining 54% are connecting, and hence make no demand on the ground transport system.

Projections of passenger enplanements for the proposed new St. Louis area have already been given on Table 3.2. The corresponding projections of originating passengers is given on Table 3.18. The number of terminating passengers is assumed to be equivalent. The diurnal variation of passenger arrival is assumed to be equal to the diurnal variation of aircraft activity for St. Louis, as given on Table 3.11. There is, perhaps, a slight difference in phase between aircraft movements and passenger movements but this is most probably less than an hour and will be ignored. Also, data is available[11] which shows that there is a slight difference in enplaning and deplaning passenger diurnal patterns. The morning hours (7:00 AM - 10:00 AM) show a larger number of enplaning passengers than deplaning, and the late night hours (9:00 PM - 12:00 PM) show the opposite. It is not possible, however, to include this effect, for to do so would require data that is consistent with the aircraft activity pattern on Table 3.11. This information was not

Table 3.18

Annual Air Carrier Originating Passengers*

St. Louis Airport

Source	Millions of Passengers					
	1975	1980	1985	1990	1995	2000
NADC	-	3.1	4.8	7.2	10.5	14.3
McDonnell	2.5	4.0	6.3	9.9	-	-
Speas	2.4	3.7	5.5	8.1	10.9	14.1

*Originating passengers are approximately 46% of enplaning passengers.

available for St. Louis, hence it is assumed that during any hour there are as many enplaning as deplaning passengers. Except for the time periods mentioned above, this is a good approximation.

Passenger-Related Visitors

To estimate the number of air passenger-related visitors, the results of surveys at other airports were used. The ratios of visitors to passengers are available for Cleveland's Hopkins Airport[18] and Chicago's O'Hare Airport[19], as well as for a number of other airports.[20, 21] Even when all the figures are reduced to the common base of total visitors per total (originating plus terminating) passengers, there is a significant variation. The ratio varies from a low of 0.17 for Miami to a high of 1.93 for Denver. The data for Cleveland in Ref. 18 (Phase I, prior to completion of the rapid transit link to the airport) shows an average ratio of 0.64 visitors per passenger, while Ref.19 shows a ratio of 0.353 on a Wednesday and 0.829 on a Saturday, leading to a weekly average of 0.444 for Chicago. In selecting the Cleveland data for application to the St. Louis airport, the following considerations were made: (a) only Refs. 18 and 19 contained diurnal variations of visitor/passenger ratios; (b) the Chicago data was collected over two days only, as compared to seven days for the Cleveland data; and (c) it was felt that the Cleveland airport would be closer in character to the St. Louis airport than would Chicago's O'Hare which is currently the busiest in the world. The visitor/passenger ratio as utilized for the St. Louis calculations are given on Table 3.19. The annual number of passenger-related visitors calculated by applying these ratios to the forecasted originating passenger ratios are given on Table 3.20. The calculated numbers are doubled to account for visitors with terminating passengers.

Table 3.19

Air-Passenger-Related-Visitor Ratios

Hour	Visitors per Passenger*
1	0.587
2	0.587
3	0.587
4	0.587
5	0.587
6	0.587
7	0.587
8	0.402
9	0.432
10	0.533
11	0.541
12	0.670
13	0.780
14	0.618
15	0.581
16	0.549
17	0.687
18	0.721
19	0.654
20	0.820
21	0.686
22	0.640
23	0.576
24	0.747

*These ratios represent visitors coming with originating passengers per originating passenger, or visitors with terminating passengers per terminating passenger, or total visitors per originating plus terminating passenger.
Source: Ref. 18

Table 3.20

Annual Passenger-Related Visitors*

St. Louis Airport

Year	Millions of Visitors NADC Forecast	McDonnell Forecast	Speas Forecast
1975	-	3.2	3.1
1980	3.9	5.0	4.7
1985	6.1	7.9	6.9
1990	9.1	12.5	10.1
1995	13.1	-	13.6
2000	17.9	-	17.7

*These figures account for visitors with originating and terminating passengers.

It might be noted parenthetically at this point that data from O'Hare is utilized elsewhere in making the calculations for St. Louis. This is not a contradiction in methodology but rather is done out of necessity. As was stated in the opening discussion of this section, there are many information gaps which must be filled in order to estimate air pollutant emissions from an airport. Wherever possible, the data which is most applicable to the study airport is used. In other cases, any data that is available is used. Hence, we can reject the O'Hare visitor/passenger data because it is felt the Cleveland data is more appropriate to St. Louis, and at the same time, utilize O'Hare information at other points because it is the best available. An argument can be made for being consistent and using O'Hare data throughout the calculation. It is felt, however, that this will result in a scaled-down picture of O'Hare and may not be as accurate a picture of St. Louis as would be this "mixed set" of data.

Employees

The employee group for an airport includes airline personnel (both passenger- and cargo-related), airport personnel (airport management, auto parking attendants, etc.,), freight forwarders, concessionnaires, and indirect support personnel (FAA, Public Health, Weather Bureau, etc.). There are two estimates of employment available for the St. Louis airport.

The NADC forecast[3] expands the 1971 employment level at Lambert Field by quantifying the workload increase, labor productivity changes, service level changes and economies of scale. Table 3.21, reproduced from the NADC study, summarizes the figures used.

Reference 22 presents another set of employment forecasts based on work done by Economics Research Associates. These are the forecasts utilized in the Environmental Impact Statement.[1]

Table 3.21 Employment Forecasts, NADC Study

St. Louis Airport

Organization or Function	Services Provided to	1971* Employment	Work Load Increase 1971-1980	Work Load Increase 1880-1985	Work Load Increase 1885-1990	Productivity Adjustment Factor 1971-1980	Productivity Adjustment Factor 1880-1985	Productivity Adjustment Factor 1885-1990	Employment Forecasts 1980	Employment Forecasts 1985	Employment Forecasts 1990
1. Airport Management	Passengers	116	2.40	1.54	1.49	.91	.90	.95	254	354	501
	Aircraft	51	1.15	1.22	1.18	.91	.86	.95	54	56	63
	Cargo	3	3.70	1.97	1.81	.91	.82	.95	10	16	28
2. Airlines	Passengers	272	2.40	1.54	1.49	1.00	.82	1.00	652	827	1,229
	Aircraft	1,453	1.15	1.22	1.18	.91	.91	.95	1,527	1,684	1,886
	Cargo	91	3.70	1.97	1.81	.84	.71	.86	282	394	615
3. Air Cargo Handlers	Cargo	181	3.70	1.97	1.81	.84	.78	.91	561	864	1,416
4. Ground Transportation	Passengers	266	2.40	1.38	1.36	.91	.91	.95	583	727	942
5. Automobile Parking	Passengers	90	2.40	1.38	1.36	.91	.91	.95	197	246	319
6. Aircraft Fueling	Aircraft	72	1.15	1.22	1.18	1.00	1.00	1.00	83	101	119
7. Concessions	Passengers	341	2.40	1.54	1.49	.91	.95	.95	748	1096	1549
8. Skycaps	Passengers	35	2.40	1.54	1.49	1.00	1.00	1.00	88	135	200
9. U.S. Post Office	Air Mail	155	2.40	1.54	1.47	.84	.91	.91	311	435	580
10. Nat'l. Weather Serv.	Gen'l Public	50	-	-	-	-	-	-	50	50	50
11. Other U. S. Gov't. Agencies	Aircraft	192	1.15	1.22	1.18	.91	.91	.91	202	224	244
12. Air Taxi & Fixed Base Operators	Passengers	75	-	-	-	-	-	-	125	150	180
13. Hotel	Passengers	0	-	-	-	-	-	-	100	200	300
		3,443							5,827	7,559	10,221

---

*Excludes headquarters personnel of Ozark Airlines and U.S. Military personnel (Army, Navy, Marines and Air National Guard).

NOTE

Airline employment expanded by 300 jobs to compensate for the reduction in normal manpower requirements occasional by current economic decline.

Since it is desired to estimate the airport emissions up to the year 2000, it is necessary to extrapolate the employee forecasts. Because of the rapid growth rate in the number of employees in the forecast period, it was decided to extrapolate the employee/enplaned passenger ratio instead of the employment itself, and then apply this value to the enplaned passenger forecast. This is a more desirable approach since the ratio tends to level off in the later years of the forecast period. The results of this procedure are given on Table 3.22 as employee forecasts for the entire period.

The diurnal pattern of employee arrivals and departures exhibits three distinct peaks corresponding to the three work shifts. A diurnal distribution of employee trips to and from work has been compiled from several airports[11] and Table 3.23 is drawn from this information. The table presents the percentage of employees arriving and departing during a given hour.

For the purposes of calculating employee trips, it is assumed that there is a 6% absentee rate. This figure is based on Cleveland data.[18]

Casual Visitors

The casual visitor group includes those who come to the airport to sightsee and tour, dine at the restaurants, secure trip information or tickets, or conduct business. This represents a small but significant fraction of the total airport population. Based on the Cleveland data[18], it can be assumed that casual visitors amount to 9% of the enplaning passenger activity. This is an extremely approximate figure, since the number of casual visitors depends so heavily on the facilities available at the airport which will attract this group. Table 3.24 presents the number of casual visitors for the St. Louis airport as calculated from the enplaned passenger forecasts.

The diurnal variation of casual visitor arrivals and departures is given in Table 3.25 and is obtained from a compilation of data on several airports.[11]

Table 3.22

Employee Forecasts

St. Louis Airport

	Number of Employees	
Year	NADC Study	ERA Study
1971	3443	3443
1975	4420+	5141+
1980	5827	6710
1985	7559	9360+
1990	10221	13521
1995	13865*	18172*
2000	18597*	23639*

* Extrapolated

+ Interpolated

Table 3.23

Airport Employee Diurnal Arrival and Departure Pattern

Hour	Percentage of Employees Arriving	Percentage of Employees Departing
1	0.1	3.0
2	0.1	0.5
3	0.3	0.7
4	0.3	0.3
5	1.3	0.2
6	5.3	0.4
7	27.3	1.0
8	19.1	3.5
9	4.5	1.3
10	2.8	2.0
11	3.0	2.2
12	1.7	3.5
13	4.0	1.2
14	5.6	3.0
15	8.8	6.1
16	4.0	25.0
17	1.9	14.9
18	0.5	6.0
19	1.3	3.6
20	1.0	3.0
21	0.9	3.0
22	0.3	2.8
23	5.0	5.0
24	0.9	7.8
	100.0%	100.0%

Table 3.24

Annual Airport Casual Visitors

St. Louis Airport

	Thousands of Visitors		
Year	NADC Forecast*	McDonnell Forecast*	Speas Forecast*
1975	--	493	477
1980	608	786	729
1985	943	1233	1080
1990	1418	1944	1575
1995	2046	-	2124
2000	2790	-	2763

*Casual visitor projections based on 9% of the forecasted enplaning passenger rate.

Table 3.25

Airport Casual Visitor Diurnal Arrival and Departure Pattern

Hour	Percentage of Casual Visitors Arriving	Percentage of Casual Visitors Departing
1	0.2	0.2
2	0.2	0.2
3	1.5	1.5
4	0.0	0.0
5	0.6	0.1
6	0.1	1.3
7	1.5	0.2
8	3.2	0.2
9	0.0	0.1
10	9.7	2.8
11	2.0	6.9
12	2.6	3.9
13	4.7	4.2
14	3.0	3.8
15	2.6	3.7
16	5.5	2.5
17	3.5	4.1
18	6.1	3.4
19	15.4	7.0
20	20.4	12.0
21	7.5	18.5
22	4.0	15.3
23	2.7	3.8
24	3.0	4.3
	100.0%	100.0%

Summary of Person Trips

Table 3.26 summarizes the manner in which person trips to and from the airport are itemized. The format is general, although the assumptions which were made to fill in the data gaps lead to a considerable simplication of the calculations.

The first assumption entails the equivalence of the originating and terminating passenger rates and the diurnal pattern of each. The rates must be almost equal over any appreciable averaging period unless there were some unusual "source" or "sink" of passengers. As previously noted, the difference in diurnal patterns between enplaning and deplaning passengers could not be accounted for due to lack of data applicable to St. Louis and consistent with the aircraft activity pattern.

The equivalence of the visitor groups with originating passengers and meeting terminating passengers appears to be a reasonable assumption since the visitor/passenger ratio was developed[18] for both originating and terminating passengers. The assumption that the departing visitors (both leaving originating passengers and having met terminating passengers) have the same diurnal pattern as the arriving visitors implies that visitors are at the airport on the average for less than an hour. This is a good assumption based on experience at other airports.[23, 24] The average time an automobile used to transport air passengers is parked is on the order of 1.4 hours (excluding long-term parking in excess of 12 hours, which represents air passengers who have driven to the airport themselves and parked for the duration of their trip).[25] If, in the averaging procedure, those autos which were used to transport air passengers but which did not park (e.g., unloaded the passengers and then departed) were included, this average would probably be reduced to less than one hour. Hence, the equal diurnal distributions of arriving and departing visitors is taken to be a good approximation.

Table 3.26

Summary of Daily Person Trips To and From Airport

St. Louis

Trip	Source of Information Activity Level	Diurnal Pattern
Arriving		
1. Originating Passengers	NADC,[3] McDonnell,[4] Speas[2] Studies	Aircraft Activity Diurnal Pattern
2. Visitors with Originating Passengers	Application of Visitor/Passenger Ratio of Ref. 18	
3. Employees	6% Absentee Rate from Ref. 18. NADC Study, Ref. 22	Ref. 11
4. Casual Visitors	9% of Enplaning Passenger Rate from Ref. 18	Ref. 11
5. Visitors Meeting Terminating Passengers	Equal to Visitors with Originating Passengers	Equal to Visitors with Originating Passengers
Departing		
1. Terminating Passengers	Equal to Originating Passenger Level	Equal to Originating Passenger Pattern
2. Visitors with Terminating Passengers	Equal to Visitors Meeting Terminating Passengers (Group 5 - Arriving)	Equal to Visitors Meeting Terminating Passengers (Group 5 - Arriving)
3. Employees	Equal to Employees Arriving	Ref. 11
4. Casual Visitors	Equal to Casual Visitors Arriving	Ref. 11
5. Visitors Leaving Originating Passengers	Equal to Visitors with Originating Passengers (Group 2 - Arriving)	Equal to Visitors with Originating Passengers (Group 2 - Arriving)

Modal Choice

Once the pattern of person trips to and from the airport has been established, the next step in proceeding to the vehicular activity pattern is to determine a ground transportation mode choice or modal split for each of the traveling groups previously defined.

For the passenger group, the mode choice is obtained from the Impact Statement.[1] This is information collected at Lambert Field in St. Louis and is therefore specific to the St. Louis area. It is assumed that there is no change in modal choice over the forecast period. There is some indication[18] that for the passenger group there is some variation in mode choice during the day, but this is not very dramatic and will not be incorporated here due to the lack of data relevant to St. Louis.

It should be pointed out that if the Cleveland data[18] for diurnal mode choice were to be used, the constraint of having to match the daily average modal choice and the diurnal passenger pattern given for St. Louis must be applied. The Cleveland data cannot, in fact, meet this constraint and, in general, should not be expected to meet it. This is because the Cleveland data has its own diurnal variation of person-trips built into it. This illustrates one of the cautions which must be exercised in applying information from other airports to the study airport. Once some information is obtained from the study airport and is to be used in the activity projections, all other data must then be chosen to be compatible with this information. The compatibility situation appears most often in applying diurnal patterns and then constraining these to match some given daily average. The mode choice situation above and the previously discussed differences in the originating and terminating passenger diurnal patterns illustrate this compatibility problem.

area facing Chicago, manufacturing and warehousing increased approximately 37% from 1960 to 1970, while in the opposite quadrant, facing away from Chicago, manufacturing and warehousing activity increased approximately 250% during the same period. The absolute magnitudes of the growth on either side of the airport site were comparable.

The Relative Contribution of Land Use Activities to Airport Area Air Pollutant Emissions

Manufacturing and warehousing emissions in the O'Hare Airport area study are substantially greater (by approximately an order of magnitude) than emissions from residential, commercial, or institutional sources; however,motor vehicle emissions in the study area are the dominant source of air pollutants in the airport vicinity—particularly, in the case of carbon monoxide, hydrocarbons, and nitrogen oxides. Even after a 90% emission reduction is realized as a result of applying the Federal Emission Standards, For passenger-related visitors, the modal choice is gotten from the Cleveland data[18]. It is assumed that visitors with originating passengers and visitors with terminating passengers have the same mode choices. No information was available on the diurnal variation in mode choices.

For employees, the modal choice is based on an average of ten airports.[11] Again, there was no information available on diurnal variation in mode choice.

For casual visitors, the modal choice is also gotten from a ten airport average.[11] No diurnal variation information was presented.

Table 3.27 summarizes the modal choice of each of the considered groups and indicates the source of the information.

Vehicle Loading Factors

The next step in generating vehicle activity is to apply a vehicle load factor (persons per vehicle) to the number of people using each mode. The load factors are developed separately for each group since there is a considerable variation.

The passengers and passenger-related visitors are treated together since they, in general, travel together. The employees and casual visitors are treated as separate groups. People from all groups who use mass transit are included in a separate group because they all travel together. Table 3.28 summarizes the load factors used.

For autos, the load factors are based on an average of ten airports surveyed.[11] It can be seen that employees are heavily weighted toward the lone-driver end of the spectrum while the casual visitors gravitate toward the driver-plus-several passenger end.

The taxi and limosine load factors are based on observations made at the terminal ramps of Chicago's O'Hare airport.[13] Since this was the only information available on taxi loadings, it was applied to both the passenger and employee groups.

Table 3.27

Modal Choice Summary

St. Louis Airport

% of Group Using Mode

Mode Group	Private Auto	Rental Auto	Taxi	Limosine	Bus	Source of Information
Passengers	65.0	11.0	13.0	2.0	9.0	Ref. 1
Passenger-Related Visitors	95.4	1.2	1.1	1.7	0.6	Ref. 18
Employees	91.6	0.	1.1	0.	7.3	Ref. 11
Casual Visitors	97.5	0.	0.1	0.	2.4	Ref. 11

Table 3.28

Vehicle Load Factors

St. Louis Airport

Persons per Vehicle Trip

Mode Group	Private Auto	Rental Auto	Taxi	Limosine	Bus	Commuter Train-Diesel	Rail Transit-Electric
Passengers Passenger-Related Visitors	1.79	1.15	1.65	2.82			
Employees	1.15	--	1.65	--			
Casual Visitors	2.89	--	1.65	--			
All People Using Public Transit					38	563	300

There was no information available on rental auto load factors and time did not permit the making of direct observations. It was decided to use the auto load factor for employee trips since this probably came closest to approximating the predominately business character of rental car useage.

The bus, commuter train and rail transit load factors were derived from information in Ref. 26. (Although there are no current plans for a rail link to the proposed new St. Louis airport, the rail factors are presented for use in a trade-off study on alternative means of airport access. This will be discussed later.) Mass transit tends to operate on a schedule, rather than on a daily demand basis. In projecting the transit trips it can be assumed, nevertheless, that the schedule will over the course of time reflect the actual demand for travel. Therefore, to develop the vehicle load factors it is assumed that in any hour in which there are enough people seeking to use a mass transit mode to make up 75% of the capacity of a mode trip, an additional trip will be scheduled. Buses are assumed to have a 50-passenger capacity. Thus, whenever there are 38 people seeking to use a bus, a trip will be scheduled in that hour; hence, the vehicle load factor of 38. For a diesel commuter train, the capacity is 750 passengers (5 cars at 150 passengers per car) and for an electric rail transit, it is 400 (5 cars at 80 passengers per car).[26] The 75%-capacity trip generator produces vehicle load factors of 563 and 300, respectively.

Truck Trips

Airports are not generators of large numbers of truck trips; surveys at Los Angeles airport and San Francisco airport[11] show that trucks account for only 2% and 5%, respectively, of total vehicle trips. For O'Hare airport in Chicago trucks accounted for only 30% of the traffic in the cargo area.[13] The cargo area itself accounts for less than 10% of the total traffic at O'Hare; hence the San Francisco, Los Angeles and Chicago data consistently point to the small fraction of truck trips. For the sake of completeness, these trips will be included in the total ground vehicle access accounting.

A good estimate of truck trips can be made by applying a proportional factor to the employee person-trips. Based on studies at 5 other airports,[11] an average value of this factor is 0.128 truck trips per employee person-trip. Table 3.29 gives the total number of daily truck trips for the NADC and the ERA employee forecasts of Table 3.22 (assuming a 6% absentee rate) for the St. Louis airport based upon this factor. This puts the truck trips for St. Louis in the range of 2-3% of total trips which is consistent with the aforementioned data.

Based on the information at other airports, a diurnal pattern for truck trips can be determined.[11] Also, a distribution of trips among light-duty trucks or vans, heavy-duty gasoline-powered trucks, and heavy-duty diesel-powered trucks can be made.[13] This data is presented on Table. 3.30.

Summary of Vehicular Activity

With the above information it is possible to project the vehicular activity and mix for the study airport. Starting from the generation of the person-trips from the enplaning passenger forecasts, the calculation proceeds as follows. We define the person-trips to be A_{ij}, the number of people of group i arriving at the airport in hour j and D_{ij}, the number of people of group i departing from the airport in hour j. The A_{ij}'s and D_{ij}'s are calculated from the given information.

Table 3.29

Daily Truck Trips

St. Louis Airport

Year	From NADC Employee Forecast*	From ERA Employee Forecast*
1975	--	619
1980	701	807
1985	909	1126
1990	1230	1627
1995	1668	2186
2000	2238	2844

*Based on 0.128 truck trips per employee person-trip (including a 6% absentee rate).

Table 3.30

Diurnal Distribution of Truck Trips and Vehicle Type Distribution

St. Louis Airport

Hour	Percentage of Trucks Arriving*	Percentage of Trucks Departing*
1	2.4	2.3
2	2.4	2.2
3	2.5	2.2
4	2.5	2.2
5	2.5	2.2
6	2.5	2.2
7	3.4	2.5
8	3.8	3.2
9	6.5	7.0
10	6.2	6.7
11	6.2	6.7
12	4.9	6.0
13	5.5	5.0
14	6.0	5.9
15	5.8	5.9
16	5.3	5.5
17	5.5	4.0
18	6.0	5.2
19	5.1	5.5
20	3.8	4.3
21	3.7	4.2
22	3.0	3.5
23	2.3	2.6
24	2.2	3.0
	100.0	100.0

Percentage Distribution**

Light Duty Trucks	Heavy Duty Gasoline-Powered Trucks	Heavy Duty Diesel-Powered Trucks
30.3	51.6	18.1

---

* From Ref. 11

** From Ref. 13

$$
\begin{aligned}
A_{1j} &= E \times F_{1j} \\
A_{2j} &= A_{1j} \times R_j \\
A_{3j} &= W(1-a) \times F_{3j} \qquad\qquad (1a) \\
A_{4j} &= CV \times F_{4j} \\
A_{5j} &= A_{2j}
\end{aligned}
$$

where A_{1j} is the number of originating passengers arriving at the airport in hour j, E is the daily originating passenger rate from the study forecasts (Table 3.18), and F_{1j} is the fraction of originating passenger arriving in hour j (Table 3.11); A_{2j} is the number of passenger-related visitors arriving in hour j and R_j is the visitor/passenger ratio (Table 3.19); A_{3j} is the number of employees arriving in hour j, W is the number of employees from the projection (Table 3.22), a is the absentee rate (6%), and F_{3j} is the fraction of employees arriving during hour j (Table 3.23); A_{4j} is the number of casual visitors arriving in hour j, CV is the daily number of casual visitors (Table 3.24), and F_{4j} is the fraction of casual visitors arriving in hour j (Table 3.25); A_{5j} is the number of visitors meeting terminating passengers in hour j.

For the departing trips, if we define D_{1j} as terminating passengers, D_{2j} as visitors with terminating passengers, D_{3j} as employees, D_{4j} as casual visitors, and D_{5j} as visitors having left originating passengers in hour j, and if we make previously discussed assumptions, we have the following:

$$
\begin{aligned}
D_{1j} &= A_{1j} \\
D_{2j} &= D_{1j} \times R_j \\
D_{3j} &= W(1-a) \times G_{3j} \qquad\qquad (1b) \\
D_{4j} &= CV \times G_{4j} \\
D_{5j} &= A_{2j}
\end{aligned}
$$

where G_{3j} and G_{4j} are the fractions of employees and casual visitors leaving in hour j (Tables 3.23 and 3.25).

To generate the vehicle trips, we apply the mode choice and vehicle load factors from Tables 3.27 and 3.28, respectively. The result is the following set of equations:

$$\begin{aligned} B_{ijk} &= A_{ij} \times C_{ik} && i=1,5 \quad j=1,24 \quad k=1,7 \\ DB_{ijk} &= D_{ij} \times C_{ik} && (2) \end{aligned}$$

$$\left.\begin{aligned} v_{1jk} &= (B_{1jk} + B_{2jk})/LF_{1k} \\ v_{3jk} &= B_{3jk}/LF_{3k} \\ v_{4jk} &= B_{4jk}/LF_{4k} \\ v_{5jk} &= (DB_{1jk} + DB_{2jk})/LF_{1k} \end{aligned}\right\} \quad k=1,4 \qquad (3a)$$

$$\begin{aligned} V_{jk} &= \sum_i v_{ijk} && k=1,4 \\ V_{jk} &= \sum_i B_{ijk}/PLF_k && k=5,7 \end{aligned} \qquad (3b)$$

k=1 private auto
2 rental auto
3 taxi
4 limosine
5 bus
6 commuter train - diesel
7 rail transit - electric

$$\left.\begin{aligned} dv_{1jk} &= v_{5jk} \\ dv_{3jk} &= DB_{3jk}/LF_{3k} \\ dv_{4jk} &= DB_{4jk}/LF_{4k} \\ dv_{5jk} &= v_{1jk} \end{aligned}\right\} \quad k=1,4 \qquad (4a)$$

$$\begin{aligned} DV_{jk} &= \sum_i dv_{ijk} \qquad && k=1,4 \\ DV_{jk} &= V_{jk} && k=5,7 \end{aligned} \qquad (4b)$$

where B_{ijk} is the number of people of group i arriving in hour j using mode k and DB_{ijk} is the corresponding number for departing people; C_{ik} is the modal choice of group i; LF_{ik} is the vehicle load factor for group i and mode k and PLF_k is the load factor for the mass transit modes; v_{ijk} are the number of vehicle trips of mode k made by people of group i in hour j; and V_{jk} are the total number of vehicle trips of mode k made in hour j. For departing vehicle trips dv_{ijk} and DV_{jk} are the corresponding values.

The truck trips are obtained by taking the proportioned ratio to employee person-trips (Table 3.29) and applying the diurnal pattern and vehicle type distribution (Table 3.30). This leads to the following equations:

$$V_t = W(1-a) \times 0.128 \qquad (5)$$

$$V_{j8} = V_t \times T_j \times 0.303$$
$$V_{j9} = V_t \times T_j \times 0.516 \qquad (6)$$
$$V_{j10} = V_t \times T_j \times 0.181$$

k=8 light-duty truck
k=9 heavy-duty, gasoline-powered truck
k=10 heavy-duty, diesel-powered truck

$$DV_{j8} = V_t \times DT_j \times 0.303$$
$$DV_{j9} = V_t \times DT_j \times 0.516 \qquad (6b)$$
$$DV_{j10} = V_t \times DT_j \times 0.181$$

where V_t is the total number of truck trips per day, T_j is the fraction of trucks arriving in hour j, and V_{jk} is the number of trucks of type k arriving in hour j. DT_j and DV_{jk} have corresponding meanings for departing trucks.

The assumptions which were used to develop the person-trip projections as given by Equation 1 have already been discussed. Several additional assumptions are implied by Equations 2, 3, 4. They are the following:

- The mode choice, C_{jk}, is the same for arriving and departing people. (The Environmental Impact Statement[1] shows that actually there is a slight change in modal choice between originating and terminating passengers.)
- Visitors are parked on the average less than an hour. ($dv_{1jk} = v_{5jk}$ and $dv_{5jk} = v_{1jk}$)
- The load factors for employees and casual visitors are the same for arriving and departing trips.

- All mass transit vehicles remain at the airport for less than an hour.

Figure 3.2 is a plot of the hourly vehicle trips to and from the airport for the 1990 Speas forecast.

The early morning peak of arriving first-shift employees is clearly discernable as is their late afternoon departure. It can be seen that the late afternoon - early evening is the time of maximum access traffic activity. This is a result of the departure of first-shift employees, the arrival of second-shift employees, and the maximum air passenger activity. This pattern is fairly consistent for all airports. Table 3.31 gives the daily vehicular traffic for the forecast years of the NADC, McDonnell, and Speas Studies. The traffic volumes projected by this model are comparable to those previously made for the St. Louis area.[1,27] The previous projections estimate between 70,000 and 108,000 one-way vehicle trips per day for an annual enplaning passenger rate of 17.5 million in 1990. This model estimates 106,000 for the same passenger activity (Speas forecast).

Vehicle Mileage and Operational Characteristics

With the ground access vehicle activity and mix determined by the previous analysis, the two additional pieces of information needed to complete the data set for air pollutant emission calculations are the mileage traveled by the vehicles in the airport and the operating characteristics of the vehicles.

The Environmental Impact Statement[1] suggests for St. Louis a value of 3.5 miles as an average trip length from the freeway collection point

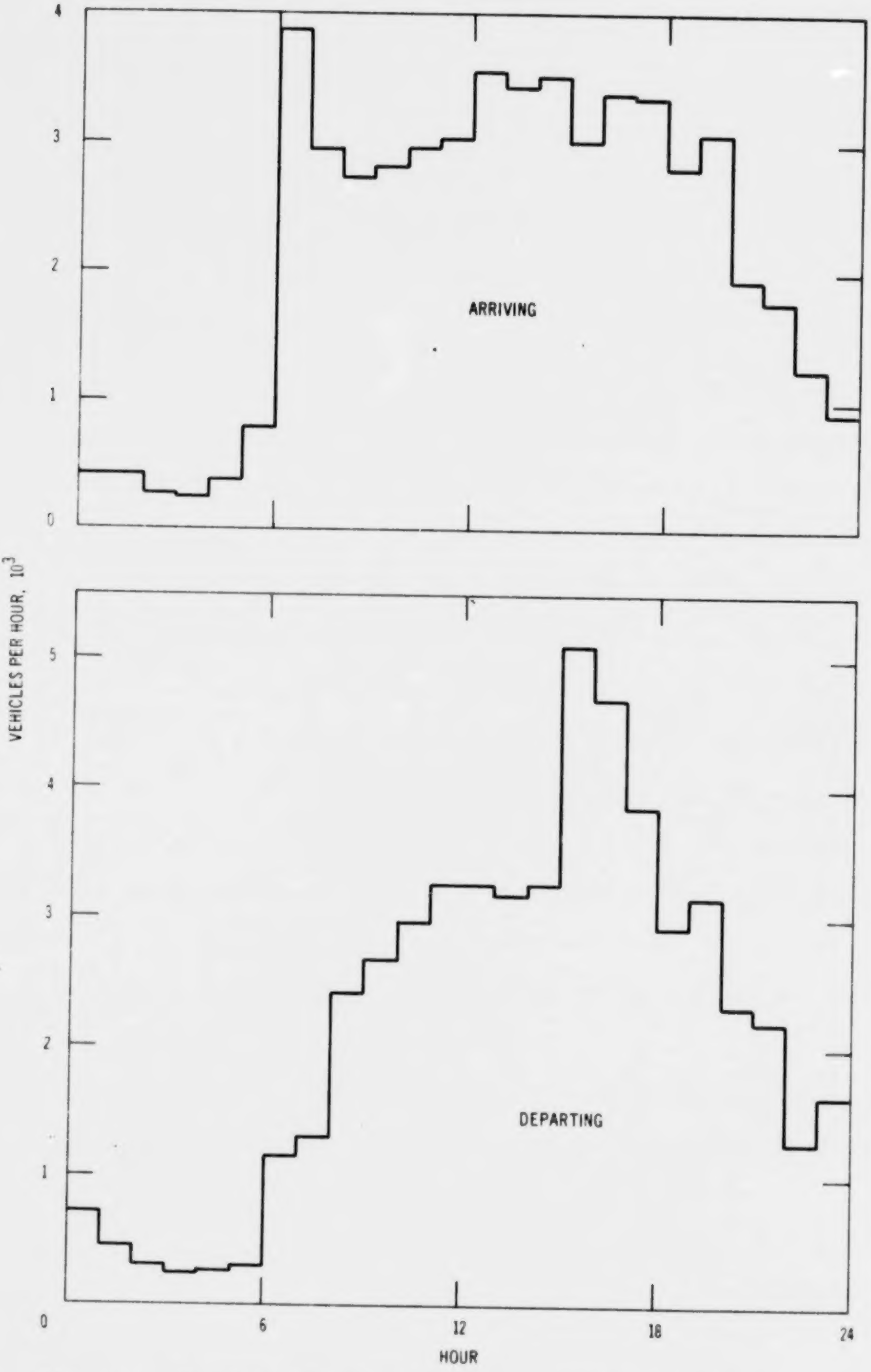


Fig. 3.2 Hourly Access Traffic Volume, 1990 Speas Forecast St. Louis Airport

Table 3.31

Daily Vehicular Access Trips*

St. Louis Airport

Year	NADC	McDonnell	Speas
	Thousands of Vehicle-Trips		
1975	-	35	34
1980	42	53	50
1985	62	81	73
1990	92	125	106
1995	131	-	142
2000	178	-	185

*Includes arriving plus departing trips.

to some central destination at the airport. Although trip lengths vary considerably with trip purpose[13], a justifiable distinction cannot be made without at least a preliminary layout of the airport site. Since this will not be available until the master plan for the airport is drawn up, the 3.5 mile average was applied across the board to all one-way trips.

From an emission standpoint, the important characteristics of vehicle operation are the average speed and the number of engine start-ups that occur after the vehicle has been allowed to cool to ambient temperature (cold start).

For an airport, there are several different speed ranges used by vehicles. There are stretches of limited access roadway where the speed limit is 50 mph or more; there are the terminal ramps where speed can go to 30 mph; and there are the low speed areas such as the parking lots and the loading areas. For the purposes of this calculation, it will be assumed that the average vehicle speed is 25 mph in an urban pattern as defined by the federal automotive test cycle. This cycle includes stop-and-go portions and should be adequate to represent airport travel.

As previously noted, it is assumed that all visitors arrive and depart the airport within the same hour. Since the time it takes a vehicle engine to cool to ambient temperature is on the order of 8-12 hours, these vehicles are not subject to a cold start on the airport grounds. The Environmental Impact Statement shows, however, that about 37% of the terminating passengers who depart by private auto use a car that has been parked at the airport. Since the air traveler's trip away from the airport is generally at least 8 hours, it is assumed that 37% of the private auto trips made by terminating passengers (i.e., 37% of dv_{1j1} in Equation 4a) involve a cold start.

Employee autos are parked at the airport for a time which averages close to 8 hours. Since the amount of time it takes a vehicle to fully reach cold start conditions varies seasonally, the general practice is to assume employee autos to have a 90% cold start when they are started up for the departing trip. This practice will be followed here and the vehicle trips represented by dv_{3j1} in Equation (4a) will be assumed to have a 90% cold start.

It is further assumed that all departing rental car trips (dv_{ij2}) have a full cold start.

The taxi, limosine, bus and truck trips are assumed to have no cold starts on the airport grounds.

Table 3.32 summarizes the vehicle mileage and operating characteristics.

Table 3.32

Airport Vehicle Mileage and Operating Characteristics

St. Louis Airport

Mode	Private Auto	Rental Auto	Taxi	Limosine	Bus	Commuter Train Diesel	Rail Transit Electric	Light Duty Trucks	Heavy Duty Gasoline Powered Trucks	Heavy Duty Diesel Powered Trucks
Arriving Vehicles										
Speed (MPH)	25	25	25	25	25			25	25	25
Mileage (Mi)	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5
Cold Start	None									
Departing Vehicles										
Speed (MPH)	25	25	25	25	25			25	25	25
Mileage (Mi)	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5
Cold Start	a. 37% of those used by passengers have 100% cold start b. All employee autos have 90% cold start	All have 100% cold start	None	None	None	None	None	None	None	None

3.2 Compilation of Emission Factors

The purpose of this section is to compile the various emission factors which are necessary to convert the airport activity levels into rates of air pollutant emissions. Emission factors are presented for aircraft, ground service vehicles, the fuel storage and handling system, engine test and maintenance facilities, the heating and air conditioning plant, and access traffic. Four pollutants are considered: carbon monoxide, total hydrocarbons, nitrogen oxides, and particulates. Emission factors are presented in the most frequently used units for ease of comparison. Units are adjusted in the final computations.

3.2.1 Aircraft

A substantial amount of research has been done in recent years to determine the rate of air pollutant emissions from aircraft engines. The emission factor is a function of two distinct pieces of information. The first is the actual rate of emission of an aircraft engine as a function of its power setting; the second is the amount of time the engine is operated at each power setting during the course of a landing and takeoff cycle.

Three sets of aircraft emission factors were considered for use. The first set was published by the Federal Environmental Protection Agency[28] and is given in the form of total emissions per LTO cycle. It was felt that this format was not flexible enough to provide the resolution required to determine which modes of aircraft operation were contributing most to the emission rate. Also, the engine emission rates are based on dated information and more recent and complete data is available.

The second set was based on work done by Northern Research and Engineering Corporation.[29] The data is published in a form which gives the engine emission rates and the times of engine operation in each mode and can thus be used to segregate the emission contribution. The emission rates, however, were based on only a limited number of engine tests since the more comprehensive data was not yet available at the time of the NREC work.

The third set was based on work done by the Cornell Aeronautical Laboratory [30] and by Argonne.[10] It is felt that the combination of the CAL emission rates and the Argonne engine operating times represent the most up-to-date and accurate information currently available.

The CAL engine emission rates are compiled from a substantial number of measurements made on different families of aircraft engines. The data are presented as a function of engine power setting. In tabulating the information shown on Table 3.33, the aircraft operational mode rather than engine power setting is used for ease in comparing different engine sizes.

The aircraft designations beneath each engine are designed to show which airplanes use which engine family. Although the particular aircraft may not use the specific engine shown, it uses one that is similar. For lack of complete data for all engine types it is assumed that the aircraft considered use one of the engines tabulated in Table 3.33. The operational modes are defined on Table 3.34.

The engine emission rates compiled by CAL are used for the taxi, idle, approach, takeoff, and climbout modes. For the landing mode, a simple algebraic equation is used which reflects the effect of the utilization of thrust reversal. The equation is written as

$$E_{\text{landing}} = 0.6E_{\text{idle}} + 0.16\,E_{\text{approach}} + 0.24\,E_{\text{takeoff}}$$

where E_i is the emission factor of mode i. The weighting factors were obtained from aircraft operational experience.[16]

Since the CAL data did not include information on particulate emission rates, the NREC data [29] was used. NREC data was also used to obtain all the emission factors for the piston engine (IO-520-A) since this also was not included

Table 3.33 Air Pollutant Emission Rates of Aircraft Engines

Aircraft Class	Engine Type (Aircraft)	Mode	Emission Rate (lb/hr/eng)			
			CO	HC	NO_X	PT
Jumbo	JT9D B747 DC10 L1011	Taxi	86	19	6	0.6
		Idle	86	19	6	0.6
		Landing	59	12	174	0.7
		Takeoff	6	2	672	0.9
		Approach	38	3	54	0.6
		Climbout	11	2	425	0.9
Long Range	JT3D B707 DC8	Taxi	103	84	1	0.3
		Idle	103	84	1	0.3
		Landing	69	55	39	2
		Takeoff	10	12	148	6
		Approach	29	12	20	5
		Climbout	10	13	94	6
Medium Range	JT8D B727 DC9 B737	Taxi	37	9	2	0.5
		Idle	37	9	2	0.5
		Landing	26	6	36	7
		Takeoff	6	0.4	133	21
		Approach	12	0.9	20	9
		Climbout	6	0.4	87	21
Short Range	A-501-D13 C580 F-27	Taxi	15	6	2	0.1
		Idle	15	6	2	0.1
		Landing	10	4	8	0.3
		Takeoff	2	0.4	23	0.6
		Approach	4	0.5	8	0.4
		Climbout	3	0.5	21	0.6
	Spey 511 BAC111 F-28	Taxi	60	66	1	0.04
		Idle	60	66	1	0.04
		Landing	46	40	42	0.3
		Takeoff	14	NA	153	0.8
		Approach	39	4.2	30	0.4
		Climbout	15	0.2	115	0.8
	Continental 10-520-A Cessna 210 Piper 32-300	Taxi	30	2	0.2	0.06
		Idle	30	2	0.2	0.06
		Landing	35	2	0.2	0.06
		Takeoff	62	1.5	0.4	0.10
		Approach	12	2.5	0.05	0.02
		Climbout	62	1.5	0.4	0.10
	Auxilary Power Unit	In Operation	2.8	0.11	1.24	Not Available

Table 3.34

Aircraft Operating Modes and the Various Activities Included in Each

Mode	Engine Operating Times Included in Mode
Taxi	Transit times between ramp and apron, apron and runway and time required for turning and alignment between taxiway and runway.
Idle	Push back from gate; waiting for signal to begin taxiing; waiting at taxiway intersections; runway queing; gate queuing.
Landing	Touchdown to beginning of taxi on taxiway.
Takeoff	After alignment with runway to liftoff.
Approach	3000 ft altitude to touchdown
Climb-out	Liftoff to 3000 ft altitude.

in the CAL work. Data for the auxiliary power unit emissions was taken from work done by Pratt and Whitney and compiled by CAL.[30]

The amount of time an aircraft spends in each mode is a variable dependent on the particular airport under study. At a given airport the times will vary with the runway utilization, congestion, and changes in operational procedures. For example, an aircraft landing on a distant runway will have a longer distance to travel to the terminal, hence a longer time spent in the taxi mode, hence a larger quantity of pollutants emitted than would the same aircraft landing on a runway near the terminal. The procedure used to generate the times given on Table 3.35 involves the averaging of many observations at O'Hare Airport and is discussed in detail in Ref. 10. While the data for O'Hare may not be the same as for the proposed new St. Louis airport, the lack of a master plan for the new airport dictates the use of the O'Hare data.

In addition to the times shown on Table 3.35, a gate occupancy time must also be included in the calculation procedure. This is necessary not only to properly reflect the diurnal pattern of activity but also to account for auxiliary power unit emissions. While an aircraft is at the gate the main engines are shut down and, if the aircraft is equipped with an APU, it is in operation for the entire gate time to provide electrical power. (If the airplane is not APU-equipped, a ground power unit must be used or a power line from the service pit is hooked up). The diurnal average gate occupancy time based on the O'Hare data is presented on Table 3.36.

3.2.2 Ground Service Vehicles

The collection of emission data for ground service vehicles presents an unusual problem. To date no comprehensive study has been undertaken to actually measure the emission rates from these vehicles even though their opera-

Table 3.35

Aircraft Times-In-Mode

	Time-In-Mode (Minutes)						
Aircraft Class	Inbound Taxi	Outbound Taxi	Idle	Landing	Takeoff	Approach	Climbout
Jumbo	7.2	7.2	4.2	0.6	0.5	3.0	1.9
Long Range	4.2	4.9	2.4	0.6	0.5	3.6	2.2
Medium Range	3.6	4.4	2.0	0.6	0.5	3.0	1.9
Short Range	3.6	4.4	2.0	0.6	0.5	4.5	3.6

Table 3.36

Aircraft Gate Occupancy Time*

Hour	Gate Occupancy Time (Minutes)
1	60.8
2	56.5
3	61.8
4	65.8
5	62.4
6	87.0
7	46.1
8	43.9
9	48.5
10	56.3
11	57.9
12	47.6
13	56.8
14	47.4
15	52.0
16	55.7
17	49.1
18	45.1
19	49.1
20	43.2
21	44.0
22	33.2
23	24.2
24	54.3

*Based on data at O'Hare International Airport, Chicago, Ref. 10

tion and maintenance characteristics differ markedly from those of private motor vehicles. The ground support equipment spends a large proportion of its total operating time motionless but with the engine at other than idle. Very little data is available on emission rates from any vehicles in this operating mode. Also, the maintenance on ground support equipment is relatively poor. With the exception of the more expensive pieces of equipment (such as the pushback tractors for the 747), the general airline feeling is that it is more cost-effective to replace a deteriorated engine in a service vehicle than it is to institute a regular maintenance program. These factors combine to make one anticipate different emission patterns between these vehicles and the normal urban traffic, even though the majority of the ground service vehicles are just specially adapted trucks from a standard production line.

As part of another airport modeling program [12], Argonne developed an indirect approach to calculate ground service vehicle emissions. Based upon a survey of ground support equipment at Chicago's O'Hare Airport, it was decided that emission data published for heavy duty trucks [31] would, if suitably adapted, provide an adequate estimate of emissions from ground service vehicles. As part of the survey personnel from the United Airlines facility at O'Hare were asked to record fuel consumed and hours of operation for a number of vehicles in their inventory. This permitted a calculation of fuel consumption rates for these vehicles. Estimates of the fuel consumption rates of other service vehicles were made based on similarities of engine type and service characteristics. These data are given on Table 3.37 for the vehicles included in this study.

To utilize the gasoline engine emission factors which are given in gms/mile and the above fuel consumption data, an estimate must be obtained for the mileage rate of fuel consumption (miles/gallon). In addition, some form of speed

Table 3.37

Ground Service Vehicles

Fuel Consumption Rates

	Vehicle	Rate of Fuel Consumption (gal/hr)
1.	Tractor	1.80
2.	Belt Loader	0.70
3.	Container Loader	1.75
4.	Cabin Service	1.50*
5.	Lavatory Truck	1.50*
6.	Water Truck	1.50*
7.	Food Truck	2.00*
8.	Fuel Truck	1.70*
9.	Tow Tractor	2.35
10.	Conditioner	1.75*
11.	Airstart	
	Transporting Engine	1.40
	Diesel Power Unit	8.20
12.	Ground Power Unit	
	Transporting Engine	2.00
	Gasoline Power Unit	5.00
	Diesel Power Unit	7.10
13.	Transporter	1.50

Data from Reference 12

*Estimated values

correction must be introduced into the emission factors to compensate for the low average speed operating characteristics of the service vehicles. The fuel consumption data serves as a constraint to this system: the ratio of the average speed (miles/hour) to the mileage fuel consumption rate (miles/gal) must equal the fuel consumption rate. There are, of course, an infinite number of combinations of average speed and mileage fuel rate which can match the consumption rate. Values which are reasonable must be chosen. Based upon an average fuel consumption rate of 1.67 gal/hr and an estimate of average vehicle speed of 10 mph the mileage fuel consumption rate is computed to be 6 miles/gal. This appears to be within expectations for this type of vehicle. With these estimates, the emission factors can be adapted to the service vehicles. This method need not be applied to diesel engines since the emission factors are already in the form of gms/gal.

For this study two sets of basic emission data have been used to develop ground service vehicle emission factors. The first set is referred to as the "uncontrolled emissions" and represents emissions that are based on the assumption that ground service vehicles will not be subject to the same emission controls as are private motor vehicles. In fact, current legislation does not apply to off-road vehicles and therefore the ground support equipment is not subject to control. The second set is referred to as the "controlled emissions" and assumes that the 1975-76 Federal automotive emission controls will apply to ground service vehicles also.

The basic emission data and a procedure for adapting the data to varying conditions of vehicle age distribution, average vehicle speed, and mode of operation has been published.[31] For this study the ground service vehicle age distribution is assumed to be the same as is reported for O'Hare, the average vehicle speed is assumed to be 10 mph as discussed above, and the vehicles will be assumed to operate in the "hot start" mode.

The result of making the two separate assumptions regarding emission controls results in two sets of emission factors. The uncontrolled emission factors do not change during the forecast period while the controlled emission factors change as more new vehicles are brought into the population. Table 3.38a gives the uncontrolled emission factors and Table 3.38b gives the controlled emission factors.

It will be noticed that only one emission factor is presented for all gasoline-powered ground service vehicles and only one for all diesel-powered vehicles. The data from O'Hare [12] led to the conclusion that the development of separate emission factors for each piece of equipment was not justifiable because of the engine similarities.

3.2.3 Fuel Storage and Handling System

Emissions from fuel handling and storage come from the evaporation of liquid from storage tanks during the daily temperature fluctuations and from the displacement of fuel vapors when tanks are filled. The first is called the breathing loss and the second is called the working loss.

There is also the possibility of evaporation of fuel that is spilled during aircraft and ground vehicle refueling operations. This is assumed to be negligible in this study because significant quantities of spilled fuel are generally washed away promptly by ground crews due to fire hazards. Thus the spillage is more of a water pollution than an air pollution problem.

Breathing loss is a function of the type of storage tanks, the daily temperature cycle, wind speed, fuel vapor pressure, and a number of other very specific variables. It is possible, however, to assume that breathing losses can be controlled by vapor recovery systems installed in the tanks.[28] This is true for both fixed and floating roof tanks. It seems reasonable to expect

Table 3.38a

Ground Service Vehicle Uncontrolled Emission Factors

Gasoline Engines

Pollutant / Year	Emissions (grams/gallon) CO	HC	NO_x	Particulates
1975-2000	999.0	223.2	57.0	1.8

Diesel Engines

Pollutant / Year	Emissions (grams/gallon) CO	HC	NO_x	Particulates
1975-2000	147.6	29.5	154.4	11.4

Table 3.38b

Ground Service Vehicle Controlled Emission Factors

Gasoline Engines

Pollutant / Year	Emissions (grams/gallon) CO	HC	NO_x	Particulates
1975	385.20	106.68	70.26	1.80
1980	171.72	28.98	53.76	1.32
1985	35.94	13.92	34.68	0.90
1990	21.42	8.94	22.68	0.60
1995 - 2000	Same as 1990			

Diesel Engines

Pollutant / Year	Emissions (grams/gallon) CO	HC	NO_x	Particulates
1975	128.10	22.26	184.38	5.91
1980	109.17	15.63	211.80	5.91
1985	97.50	11.40	229.20	5.91
1990 - 2000	Same as 1985			

that a fuel system installed at a new airport will make use of this technology and hence eliminate this emission source.

Even if it is assumed that the tank vapor recovery system can control working losses as well as breathing losses, the aircraft and ground service vehicle tanks are also subject to working losses. (The vapor emissions from aircraft refueling operations can be seen as density waves appearing above the wing filling ports.) Thus it will be assumed that the emissions from fuel handling and storage will result solely from working losses associated with aircraft and ground service vehicle refueling.

An empirical equation for estimating working losses has been developed by the American Petroleum Institute.[32] It is the following.

$$L = \left(\frac{3}{10000}\right) P \; V \; K_T$$

L is the loss rate in gallons per year, P is the true vapor pressure of the bulk liquid in pounds per square inch, V is volume of liquid pumped in gallons per year, and K_T is a constant which depends on V and tank capacity. A recommended value[12] for K_T is 0.25. For JP-5 jet fuel the true vapor pressure at 70°F is 1.09 psi; for gasoline used in ground service vehicles it is 7.25 psi. The emission factors can then be written in terms of pounds of emission per thousand gallons of fuel pumped using a fuel density of 6.67 lbs/gallon. These values are given on Table 3.39. Since the fuels are hydrocarbons these working losses are tabulated under hydrocarbon emissions.

3.2.4 Engine Test and Maintenance Facility

The emission rates for aircraft engines have already been tabulated in Section 3.2.1. In order to complete the set of emission factors for the engine test and maintenance operation the testing cycle and the time spent at each power setting must be specified. Data from the Los Angeles maintenance

Table 3.39

Fuel Storage and Handling System Emission Factors

Working Loss

Hydrocarbon Emissions

(pounds/10^3 gallon of fuel pumped)

Aircraft Fuel	Ground Service Vehicle Fuel
0.55	3.63

facility[14] indicates that the averate test time for engines is 25 minutes. The data also indicates that the engine is run at idle power for 75% of the time, at cruise power for 25% of the time and very seldom is maximum power used. The cruise power setting varies between 50-80% maximum power. To simplify the computations by utilizing a specified power setting for which emission factors have already been given, it was decided to utilize the approach power setting in place of the cruise setting. Approach corresponds to about 40% maximum power. It is felt that in general maintenance operations will tend to gravitate toward lower power settings during testing because of the noise and safety problems associated with operating a stationary engine at high power. Hence, the approach power approximation is probably fairly good.

Table 3.40 summarizes the assumed test conditions.

3.2.5 Heating and Air Conditioning Plant

As stated in Section 3.1.7 the most probable fuels for use in the St. Louis airport heating plant are coal and oil. The Impact Statement [1] declares that natural gas is in short supply in the area and hence it will not be included here.

Emission factors for coal and oil combustion have been published elsewhere[28]. A modification is necessary, however, to reflect conformity of the plant with appropriate state air pollution control legislation. The proposed Columbia-Waterloo site for the new St. Louis airport would subject the plant to Illinois regulations.[33]

In order to determine the appropriate emission factors and the appropriate state regulations to impose as constaints, an estimate of the heat input of the plant must be made. Using the estimates of fuel required as presented on Table 3.17 and a heating value for Illinois coal of 11,000 Btu/lb

Table 3.40

Aircraft Engine Maintenance and Test Cycle

Power Setting	Minutes per Test
Idle	18.75
Approach	6.25

Total Test Time	25 minutes

(144,000 Btu/gal for oil) the plant can be projected to have a heat input on the order of 56 x 10^6 Btu/hr. This puts it into the intermediate size range.

The State of Illinois regulations which apply to this size heating plant are given on Table 3.41. The SO_2 regulation is given as a point of information even though it is not used in this study. The CO regulation requires an estimate of the working cycle of the plant boiler. Time did not permit this to be made and hence this regulation was not used.

Application of the Illinois regulations to the published emission factors [28] gives the emission factors for the airport heating plant as shown on Table 3.42.

3.2.6 Access Traffic

In this section the emission factors for the ten modes of ground access to the airport are developed and tabulated.

Private Autos

Emission factors for private autos have been drawn from data published by the Federal EPA [28] and are based on test results for a standard urban driving cycle which includes start-up, accelerations, cruise, and decelerations over a 7.5 mile trip length. Reference 31 discusses these factors and also makes reference to the criticisms that have been leveled against them. Although there is not a universal acceptance of this data, it is felt that this is the best information currently available and should be used until better data is available. (The Federal EPA is preparing to publish revised emission factors shortly.)[44]

A procedure has been developed[31] to adapt the basic EPA emission test data for CO, HC, and NO_x to representative local conditions of vehicle age mix,

Table 3.41

Illinois Air Pollution Emission Regulations*

Applicable to New Fuel Combustion Sources

10×10^6 Btu/hr < Actual Heat Input $\leq 250 \times 10^6$ Btu/hr

Pollutant	Emission Limitation
CO	200 ppm corrected to 50% excess air
HC	None
NO_x	None
Particulates	0.1 lbs/10^6 Btu heat input
SO_2	1.8 lbs (coal-fired) 1.0 lbs (residual fuel oil fired) 0.3 lbs (distillate fuel oil fired) per 10^6 Btu heat input

*From Ref 33

Table 3.42

Airport Heating Plant Emission Factors

St. Louis Airport

Pollutant	Emissions Coal-Fired (lbs/ton)	Oil-Fired ($lbs/10^3$ gal)
CO	2.0	0.2
HC	1.0	3.0
NO_x	15.0	40.0
Particulates	2.2	14.4

average trip speed and cold start contribution. This procedure will be followed to estimate the CO, HC and NO_X emission factors for vehicles in the St. Louis area. The particulate emission factors are taken directly from Ref. 28 without modification.

The first adjustment to the basic data involves the vehicle age mix. The national age mix has a greater proportion of older cars than does the mix from urban areas. The age mix for Cook County, Illinois which includes the City of Chicago is presented in Ref. 31 and will be used as the mix for the St. Louis area.

The next adjustment is for average vehicle speed. An average urban speed of 25 mph will be used as it is felt this is a representative value for airport travel. This has already been discussed in Section 3.1.8.

The final adjustment involves the separation of the cold start contribution to the total emissions. As pointed out in Section 3.1.8, the majority of private autos travelling within the airport do not have a cold start associated with them, since they are not at the airport long enough to experience the required cold soak of 8-12 hours for a full cold start. The vehicles which do require a cold start as itemized in 3.1.8 will have this contribution added on separately.

The projections of auto emissions through the forecast period to the year 2000 include the effects of the 1975-76 emission standards. It is assumed that 1975 model year vehicles will meet the standards for CO and HC emissions and 1976 model year vehicles will meet the NO_x emission standards. It will take until around 1985 before the pre-1975 uncontrolled vehicles are phased out of the population based upon the Cook County vehicle age mix.

Rental Cars

Emissions from rental cars differ from private automobiles by virtue of the fact that rental autos are substantially newer than private autos. Rental cars are generally phased out after 6-8 months of service and new model year cars are brought into the fleet almost as soon as they are available with the transition being completed by January or February of the calendar year.[34] All rental cars will therefore be treated as less than a year old and the above-mentioned adjustments to the EPA data will be made on this basis. The effect of emission controls is included in the same manner as for private autos.

Taxis

Taxis, like rental cars, are generally newer than private autos. In the City of Chicago, taxis are banned after reaching 5 years of age.[35] Three years seems to be a practical upper limit on taxi age; hence it seems to be a reasonable approximation that 25% of the taxi fleet is made up of new vehicles, 50% are a year old, and 25% are two years old. It is assumed that taxis will meet the same emission standards as private autos.

Limousines

No data was available on limousine age distributions. These are vehicles used by hotels and motels as courtesy cars as well as being fleet vehicles used by private livery services. It is therefore assumed that limousines have the same characteristics, and therefore the same emissions, as taxis.

Buses

Buses are generally diesel-powered and hence the emission factors selected correspond to the published diesel emission factors.[31] Since no standards have been set for diesel vehicles, the only distinction made in emissions is for pre-1970 and post-1970 vehicles. The distinction is made due to the introduction of a new needle valve injector which reduced the amount of fuel that could be burned. The result was a decrease in CO and HC emissions and an increase in NO_x emissions. The Cook County vehicle age distribution is used to determine the mix of pre- and post-1970 vehicles.

There is no speed dependence of diesel emissions but there is a fuel usage dependence. A fuel consumption rate of 3 mi/gal is used since this represents an average value for diesel engines.

The cold start emission is not a distinct characteristic of diesel vehicles and hence is not separated from the overall emission.

Commuter Train-Diesel

Emission factors for diesel railroad engines have been published.[28] The emission rate is converted from gms/gal to gms/mile by applying an average fuel consumption rate. A value of 3 gal/mi is a good estimate.[26]

No standards have been set for diesel railroad engines and hence the emission does not change through the forecast period.

Rail Transit-Electric

An electrically-powered rail rapid transit system produces no emissions along its right-of-way; the generation of the electricity required to power the system does in fact result in air pollutant emissions. A 10-car train loaded with 80 passengers/car is estimated to consume 70 kw-hr/train-mile.[26] The average train length assumed in Section 3.1.8 was only 5 cars; it is not, however, possible to make a simple proportional reduction of the required power usage. Since the data used here is only an approximation, it will be assumed that 70 kw-hr/train-mile is a conservative estimate.

It will be assumed that the supplying power plant will be coal-fired and that the plant can generate approximately 2260 kw-hr per ton of coal burned based upon a coal heating value of 11,000 Btu/lb and a 35% efficiency. The air pollutant emission factors for power plants [28] are constrained to meet Illinois regulations.[33] The emission factors for the rail transit are then computed as that part of the power plant emissions which are attributable to the production of the electrical power necessary to run the system and are tabulated in the form of grams per train-mile.

Light-Duty Trucks

The basic emission test data for light-duty trucks (<6000 lbs GVW) are the same as for automobiles. The only difference in computing the corrected emission factors is the rate at which emissions increase with vehicle age. The application of appropriate deterioration factors [31] makes this compensation.

Heavy-Duty Trucks

The basic emission test data for heavy-duty gasoline-powered trucks (> 6000 lbs GVW) are tabulated in Ref. 31. Although there is some feeling that truck emissions are vehicle-weight dependent, the current EPA position is that there is not sufficient evidence to justify this distinction. Hence only one set of emission factors is presented for vehicle weights over 6000 lbs. GVW.

The calculation procedure for corrected emission factors is the same as for light-duty trucks.

Diesel Trucks

Diesel trucks are treated in exactly the same way as are buses and hence have the same emission factors.

Tables 3.43 and 3.44 summarize the emission factors for all of the ten modes of access to the airport.

Table 3.43

Ground Access Vehicle Emission Factors

Hot Operation

(gms/vehicle-mile)

		Private Auto	Rental Auto	Taxi	Limosine	Bus	Commuter Train-Diesel	Rail Transit-Electric	Light-Duty Truck	Heavy-Duty Gas Truck	Heavy-Duty Diesel Truck
1975	CO	18.51	0.52	5.66	5.66	40.43	95.30	14.06	37.31	54.72	40.43
	HC	3.98	0.32	1.15	1.15	6.66	68.00	4.21	8.16	15.72	6.66
	NO_x	5.44	3.40	3.40	3.40	64.57	102.10	216.54	6.46	11.35	64.57
	Particulates	0.10	0.10	0.10	0.10	2.00	34.00	30.94	0.10	0.10	2.00
1980	CO	3.36	0.45	0.49	0.49	35.42	95.30	14.06	14.20	25.42	35.42
	HC	0.82	0.30	0.30	0.30	4.84	68.00	4.21	3.06	7.45	4.84
	NO_x	1.67	0.50	0.50	0.50	72.04	102.10	216.54	3.49	7.85	72.04
	Particulates	0.10	0.10	0.10	0.10	2.00	34.00	30.94	0.10	0.10	2.00
1985	CO	0.65	0.45	0.49	0.49	32.50	95.30	14.06	2.69	7.58	32.50
	HC	0.33	0.30	0.30	0.30	3.78	68.00	4.21	0.69	2.75	3.78
	NO_x	0.60	0.50	0.50	0.50	76.40	102.10	216.54	1.43	5.34	76.40
	Particulates	0.10	0.10	0.10	0.10	2.00	34.00	30.94	0.10	0.10	2.00
1990-2000		SAME AS 1985									

Table 3.44

Ground Access Vehicle Emission Factors

Cold Start

(gms)

		Private Auto	Rental Auto	Taxi	Limosine	Bus	Commuter Train-Diesel	Rail Transit-Electric	Light Duty Truck	Heavy-Duty Gas Truck	Heavy-Duty Diesel Truck
1975	CO	147.97	27.26	136.37	136.37	0.	0.	0.	185.81	316.27	0.
	HC	11.88	2.74	12.46	12.46	0.	0.	0.	12.42	35.45	0.
1980	CO	58.50	23.78	25.75	25.75	0.	0.	0.	103.10	258.73	0.
	HC	5.03	2.19	2.35	2.35	0.	0.	0.	7.79	28.84	0.
1985	CO	29.00	23.78	25.75	25.75	0.	0.	0.	51.90	207.79	0.
	HC	2.59	2.19	2.35	2.35	0.	0.	0.	4.43	21.17	0.
1990-2000		SAME AS 1985									

3.3 Computation of Emissions

The purpose of this section is to describe the actual calculation procedure used to apply the emission factors of Section 3.2 to the activity levels of Section 3.1. In most cases the procedure is straightforward, requiring only simple calculations. In some cases, however, there are some subtleties which should be emphasized.

Computer programs have been written to handle the large volume of data which must be manipulated. These programs, while relatively simple in their logic, enable the investigator to explore many different sets of data and to conduct "numerical experiments" to determine the effect of certain variables and perform tradeoff analyses.

The computation procedure for each of the emission sources will be discussed separately. The actual computations will be displayed in Section 5.

3.3.1 Aircraft

Figure 3.3 gives a schematic representation of how the calculation of aircraft emissions is performed. The procedure is the same as that used in the FAA/Argonne Airport Air Pollution Study.[10]

The first step is to determine the number of arrivals of each aircraft type for each hour of the day. The aircraft activity and mix data are combined with the diurnal pattern to generate this information. The appropriate emission factors for each airplane are chosen and the times-in-mode are selected by assigning the aircraft to its range class as given in Table 3.33.

The emissions from the approach, landing and inbound taxi portions. of the LTO cycle are then computed by applying the emission factors and the time-in-mode. These emissions are tabulated as having occurred during the arrival hour.

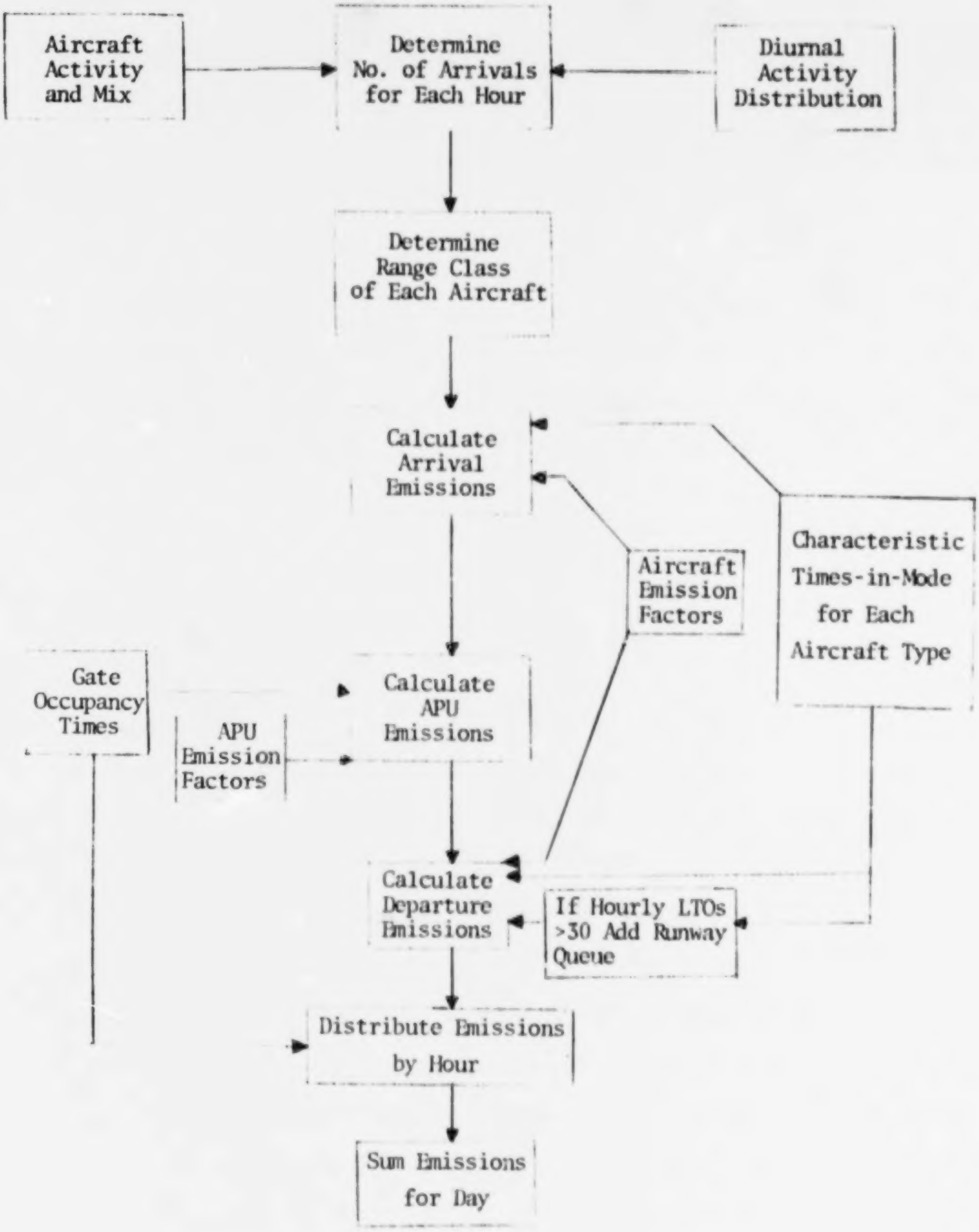

Aircraft Activity and Mix
Determine No. of Arrivals for Each Hour
Diurnal Activity Distribution
Determine Range Class of Each Aircraft
Calculate Arrival Emissions
Aircraft Emission Factors
Characteristic Times-in-Mode for Each Aircraft Type
Gate Occupancy Times
APU Emission Factors
Calculate APU Emissions
Calculate Departure Emissions
If Hourly LTOs >30 Add Runway Queue
Distribute Emissions by Hour
Sum Emissions for Day

Fig. 3.3 Aircraft Emission Calculation Procedure

The aircraft gate occupancy time as a function of the arrival hour is then determined. Those aircraft that are equipped with auxiliary power units (APUs) are assumed to have the unit in operation for the entire length of the gate time.

The next step is to compute the emissions from the departing phase of the LTO cycle. The emission factors and times-in-mode for the outbound taxi, runway idle, takeoff, and climbout are used to generate this information. At this point a check is made on the total number of LTOs occurring during the hour under consideration. If the number is less than 30, then no runway queuing time is included and aircraft are assumed to proceed immediately into takeoff position. If the number of LTOs is equal to or greater than 30, then a simple linear relationship is used to account for delay time waiting for takeoff clearance. This time is computed by the equation $T = (N-30)/10$, where T is additional runway queuing time (in minutes) during which the aircraft engines are assumed to be in the idle mode, and N is the number of LTOs in the hour. This relationship was derived from experience at Chicago's O'Hare Airport[13] and assumes the utilization of two parallel runways for airport operations.

It now remains to appropriately distribute the emissions to each hour. It has already been stated above that the emissions during the arrival segment of the LTO cycle are tabulated as having occurred during the arrival hour. If the aircraft has an APU operating during the gate occupancy period, the emissions from the first 30 minutes of gate time are included in the arrival hour. The remaining gate time APU emissions are included in the next hour. The emissions for the departure segment of the LTO cycle are included in the arrival hour if the gate occupancy time is 30 minutes or less. If it is greater than 30 minutes, these emissions are tabulated in the next hour.

The final step is to sum the total emissions for the day.

By making the calculation in this fashion, a detailed resolution of the data can be had which will enable some definitive statements to be made about the effectiveness of alternative techniques for reducing the aircraft emission load. These will be discussed in Section 5.

3.3.2 Ground Service Vehicles

The computation of ground service vehicle emissions starts with the diurnal aircraft activity pattern that has been generated as described in Section 3.3.1. Using the ground support requirements as given in Table 3.12, the number of vehicle-hours of operation for each vehicle type in each hour of the day can be computed. The results of this computation for the Speas forecast are given in Table 3.13.

The fuel consumption rate for each vehicle type is next multiplied by the operation time to generate the total amount of fuel used by all vehicles in each hour. The emission factors are applied to this number to generate the hourly ground service vehicle emissions. Both the uncontrolled and controlled emission factors are applied to investigate the differences.

It can be argued at this point that additional emissions should be added to account for intra-airport travel of service vehicles. There is data[13] to indicate that this travel can account for as much as 20% of the vehicle fuel pumped at the airport. In order to estimate this, however, some indication of airport layout must be had. For the St. Louis airport, this will not come until the master plan is drawn up.

3.3.3 Fuel Storage and Handling System

Emissions from fuel storage and handling are computed by simply applying the emission factors of Table 3.39 to the fuel requirements of Tables 3.14

and 3.15. This gives the daily emission rate. To obtain the hourly pattern, the diurnal pattern of aircraft activity is applied to the daily figure.

3.3.4 Engine Test and Maintenance Facility

The engine testing cycle is defined in Table 3.40. The emissions from a single test will depend on what engine type is being used. Since the total number of engine tests is based on a proportional ratio to the total number of aircraft LTOs, it seems reasonable to assume that the tests will have a mix of engines that is the same as the airplane mix. Also, since the maintenance facilities are set up primarily for gas turbine engines, it is assumed that only the jet engines will be serviced.

For the St. Louis airport, only the JT3D, JT8D, and JT9D engine types will be used to compute emissions. Their mix in the test facility is taken to be the same as their mix in aircraft activity (Table 3.10).

The daily total emissions are computed first and are then distributed equally over the time period of the daytime shift as discussed in Section 3.1.6

3.3.5 Heating and Air Conditioning Plant

The daily heating plant emissions are obtained by applying the emission factors of Table 3.42 to the fuel requirements of Table 3.17. The state emission regulations have already been imposed on the emission factors, hence there is no need to check for compliance. The daily emissions are distributed equally over the day.

3.3.6 Access Traffic

The procedure for calculating diurnal access traffic activity has already been described in Section 3.1.8. To proceed from activity to emissions involves first the application of the vehicle mileage traveled.

As stated previously, the one-way trip length for all ground access vehicles to the St. Louis airport was assumed to be 3.5 miles, based on information in the Impact Statement.[1] When this is multiplied by the number of vehicle trips of each vehicle type, the total number of vehicle-miles traveled by each access mode is obtained.

The hot operation emission factors for each access mode (Table 3.43) are next applied to the vehicle mileage to obtain the emissions for the hot start segment of vehicle travel.

The final step is to compute the cold start emissions. Section 3.1.8 enumerates those vehicles which are assumed to have a cold start. The emission factors of Table 3.44 are used for the computations. It should be noted that the cold start emissions are applied only to the appropriate departing vehicles.

Since the vehicle activity is developed in a diurnal pattern, the computed emissions are also diurnally distributed.

4.0 Analysis of Airport Vicinity Land Use

4.1 Methodology

A complete environmental analysis of a major airport complex must include the impact of the activities that are induced by airport development. In an effort to develop a methodology for analyzing the development in the vicinity of a major airport a case study in the vicinity of Chicago/O'Hare International Airport was conducted. The land use analysis is quite similar to the development of airport specific air pollutant emissions in that the underlying approach is to (1) identify and isolate specific activities that contribute to atmospheric emissions, (2) to quantify these activities and (3) to transform the activities into emission rate estimates. The land use study conducted in the vicinity of O'Hare focused on satisfying two basic objectives:

1) To provide a basic understanding of airport area development by means of a retrospective analysis.

2) To provide the testbed for developing and testing-land use-based emission estimates. The case study proved extremely valuable in achieving both of these objectives.

As mentioned above, the methodology for the land use analysis consisted of isolating basic activities (conventional land use or zoning classes). These activities are then quantified, emission factors applied and the spatial distribution of emissions results. This procedure is shown schematically in Fig. 4.1. The land use information was derived from aerial photographs using a unique method of photographic interpretation developed by the Northeastern Illinois Planning Commission (NIPC). The NIPC land use

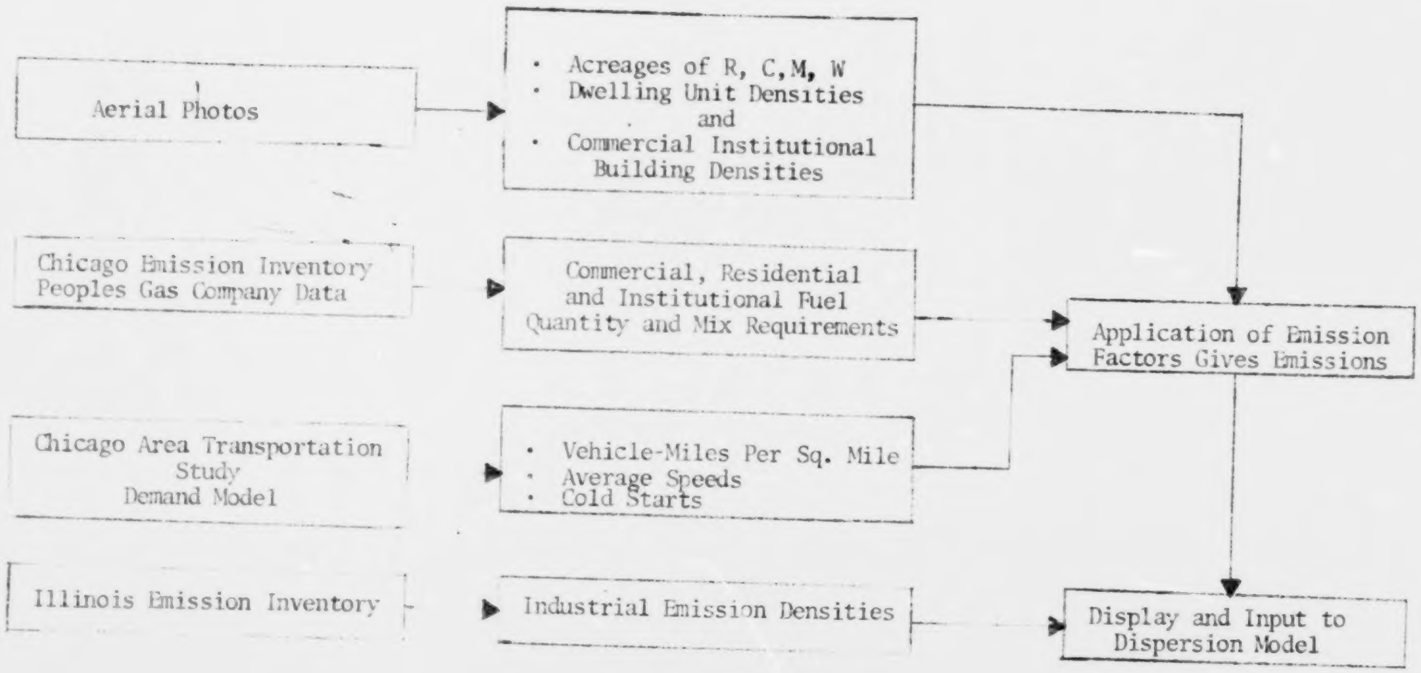

Aerial Photos
Chicago Emission Inventory
Peoples Gas Company Data
Chicago Area Transportation
Study
Demand Model
Illinois Emission Inventory
• Acreages of R, C, M, W
• Dwelling Unit Densities
and
• Commercial Institutional
Building Densities
Commercial, Residential
and Institutional Fuel
Quantity and Mix Requirements
• Vehicle-Miles Per Sq. Mile
• Average Speeds
• Cold Starts
Industrial Emission Densities
Application of Emission
Factors Gives Emissions
Display and Input to
Dispersion Model

Fig. 4.1. LAND USE BASED EMISSION ESTIMATING PROCEDURE

interpretation scheme utilizes a 24-category land use identification scheme. For simplicity, these were aggregated to nine categories which, for purposes of an air pollution analysis, are more than adequate. The nine categories utilized in this study are:

1) Residential (Single and Multi-family)
2) Residential (Mobile Home Parks)
3) Commercial
4) Industrial
5) Warehousing
6) Institutional
7) Transportation, Communications, Rights of Way
8) Vacant, Agricultural
9) Recreation, Open Space, Water

It was further assumed that, for purposes of estimating air pollutant emissions, only categories one through seven were considered to be activities having significant impact.

Ground vehicle emissions in the airport surroundings were derived from data based on the Chicago Area Transportation Study (CATS). The motor vehicle emissions were computed using the output of the CATS Demand Model which produces, on a one mile gridded basis, the vehicle miles and average speeds. State-of-the-art emission factors[28] including the local age distribution, deterioration factors and mileage estimates were applied. Ground vehicle emissions were then merged with the emissions from the original six land use categories described below to provide a complete picture of the land-use-based emissions.

The aerial photographic interpretation technique, as described in Appendix A, was applied to an area covering approximately 125 square miles covering four townships surrounding O'Hare Airport (Addison, Elk Grove, Maine and Leyden). The study area is shown in Figure 4.2. This figure illustrates the geographical relationship of the study area to the City of Chicago and the Chicago Metropolitan Air Quality Control Region. Elk Grove, Maine and Leyden townships are in Cook County and Addison township is in DuPage County. Furthermore, portions of Leyden township, as well as the airport property (approximately ten square miles), are within the corporate limits of the City of Chicago. Figure 4.2 also shows an exploded view of the study area covering the four townships, including the section numbers within each township. The aerial photographic technique yields acreages of each land use on a section-by-section basis (see Appendix B). Figure 4.2 also shows the main ground transportation routes in the airport vicinity. These major highways, as well as the airport itself, add to the induced development in the airport vicinity and are therefore very important in the land use analysis.

Aerial photograph interpretations were conducted for four years (1960, 1964, 1966, and 1970). This historical data base allowed a retrospective analysis including the trends in development of the various land use categories which parallel the growth in air carrier operations at O'Hare. Prior to 1960, O'Hare existed as a small military installation in a relatively rural area. Major construction was completed in 1959 and the airport went into large scale operations in 1960 and 1961. The land use case study of the O'Hare vicinity, therefore, will reflect growth phenomena including the effects of the airport and its associated ground transportation links.

4.2 Analysis of the Land Use Data

This section deals with the first of the earlier stated objectives related to airport area land use development; namely, to provide a basic understanding of land use development in airport vicinities.

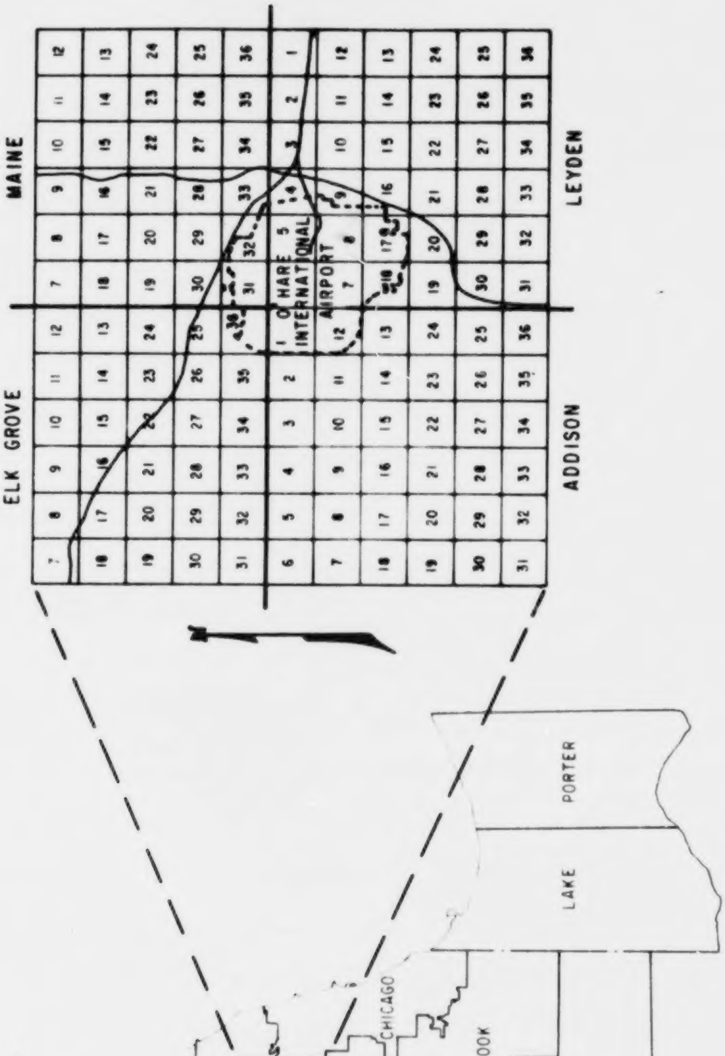

ELK GROVE
MAINE
ADDISON
LEYDEN
O'HARE INTERNATIONAL AIRPORT
McHENRY
LAKE
COOK
KANE
Du PAGE
WILL
CHICAGO
COOK
LAKE
PORTER

Fig. 4.2 Four-Township Land Use Case Study Area Surrounding O'Hare Airport

The development in the vicinity of O'Hare was analyzed using three approaches:

1) A trend analysis of each of the land use categories for the entire study area. This analysis produces an overview of the changes in each of the categories.

2) A zonal analysis based on "pie"-shaped sectors surrounding the airport. This analysis was done in an effort to indicate a directional component to the land use activities.

3) A zonal analysis consisting of concentric square rings at varying distances from the airport perimeter. This analysis was conducted to establish the relationship between growth in each of the activity classes as a function of distance from the airport.

Overall Land Use Trend Analysis

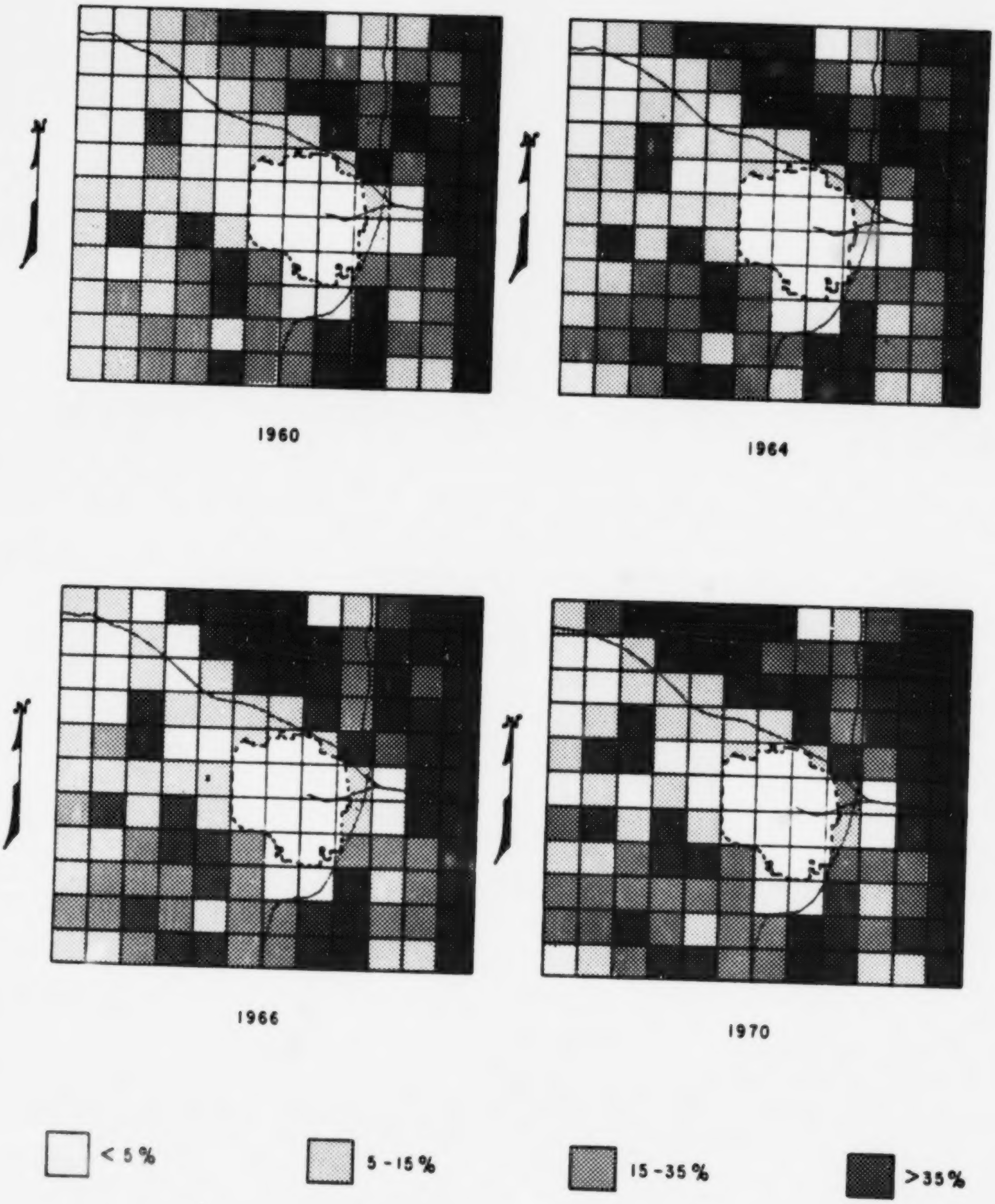
The basic seven land use classes deemed to be significant as sources of air pollutant emissions were further aggregated, primarily to reduce the analytical work load. The manufacturing and warehousing classes were combined as were the commercial and institutional. These consolodations are justified on the basis of similar fuel use demands and emission characteristics. Warehousing is considerably smaller in terms of total acreages than manufacturing, while institutional and commercial are generally comparable.

Table 4.1 and Figs. 4.3 through 4.6 show the overall land use trends for the categories under consideration. The residential land use increase (24.5% from 1960 to 1970) is considerable in view of the fact that airport operations also experienced large growth which increased the noise impacted areas. Figure 4.7 shows the growth in aircraft operations at O'Hare Airport over the same time period (aircraft landings and takeoffs are

Table 4.1 Distribution of Land Use and Trends in the Study Area

	Residential Single, Multiple and Mobile Home Parks			Commercial and Institutional			Manufacturing and Warehousing		
	Acres	% of Study Area	% Change From 1960	Acres	% of Study Area	% Change From 1960	Acres	% of Study Area	% Change From 1960
1960	18662	23.2	--	3121	3.9	--	2511	3.1	--
1964	20380	25.3	9.2	3879	4.8	24.3	3337.	4.2	32.9
1966	21888	27.2	17.3	4255	5.3	36.3	3981	4.9	58.5
1970	23280	28.9	24.5	5072	6.3	62.5	5125	6.4	104.1

	Transportation, Communications and Utilities			Vacant and Agricultural			Recreation, Open Space and Water		
	Acres	% of Study Area	% Change From 1960	Acres	% of Study Area	% Change From 1960	Acres	% of Study Area	% Change From 1960
1960	14856	18.5	--	30255	51.4	--	11088	13.8	--
1964	15912	19.8	7.1	25394	45.9	-16.1	11592	14.5	4.5
1966	16662	20.7	12.2	22990	41.9	-24.0	10770	13.4	-2.8
1970	18836	23.4	26.8	17024	35.1	-43.7	11199	13.9	1.0



1960

1964

1966

1970

N
< 5%
5 - 15%
15 - 35%
> 35%

Fig. 4.3 RESIDENTIAL LAND USE

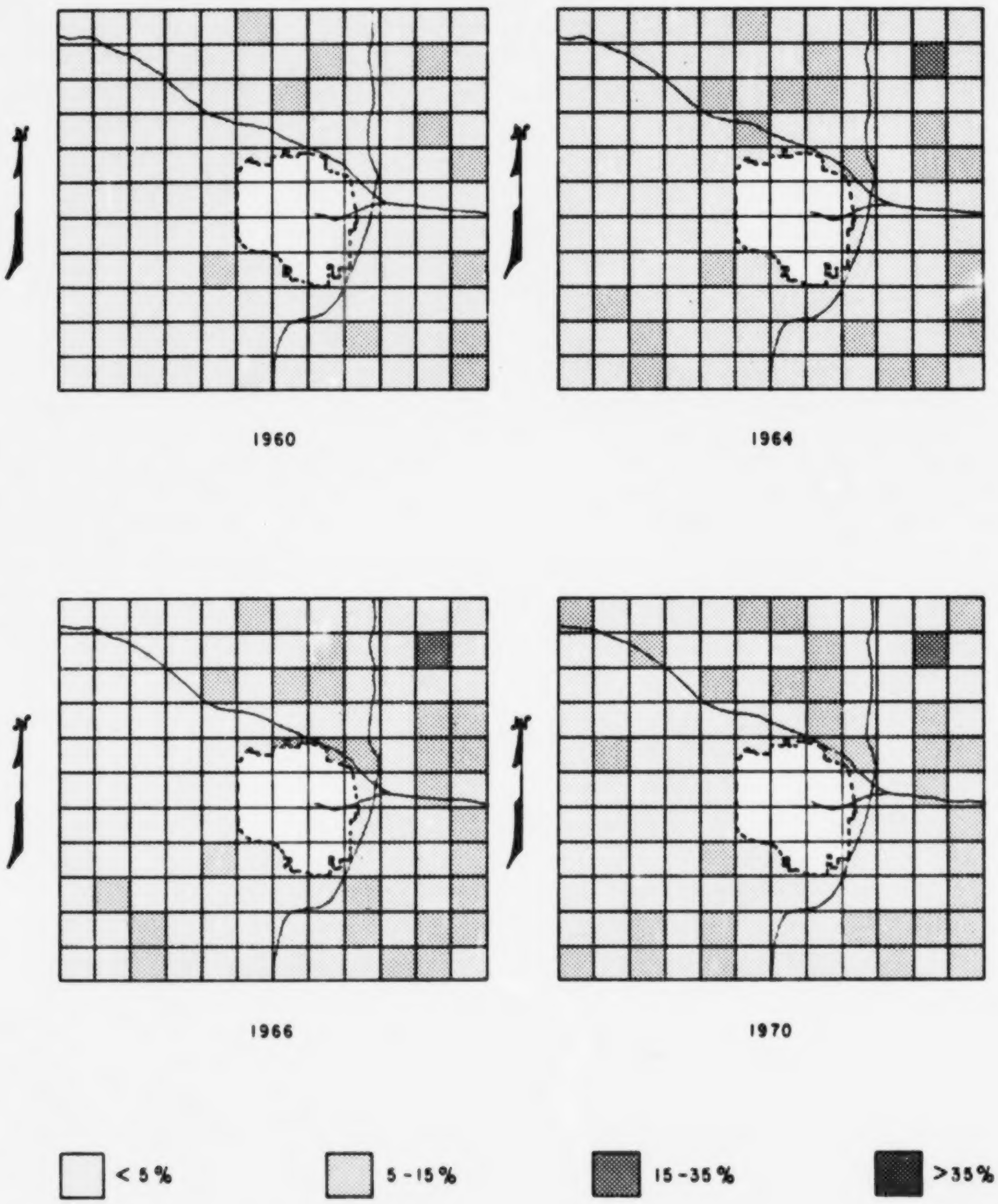
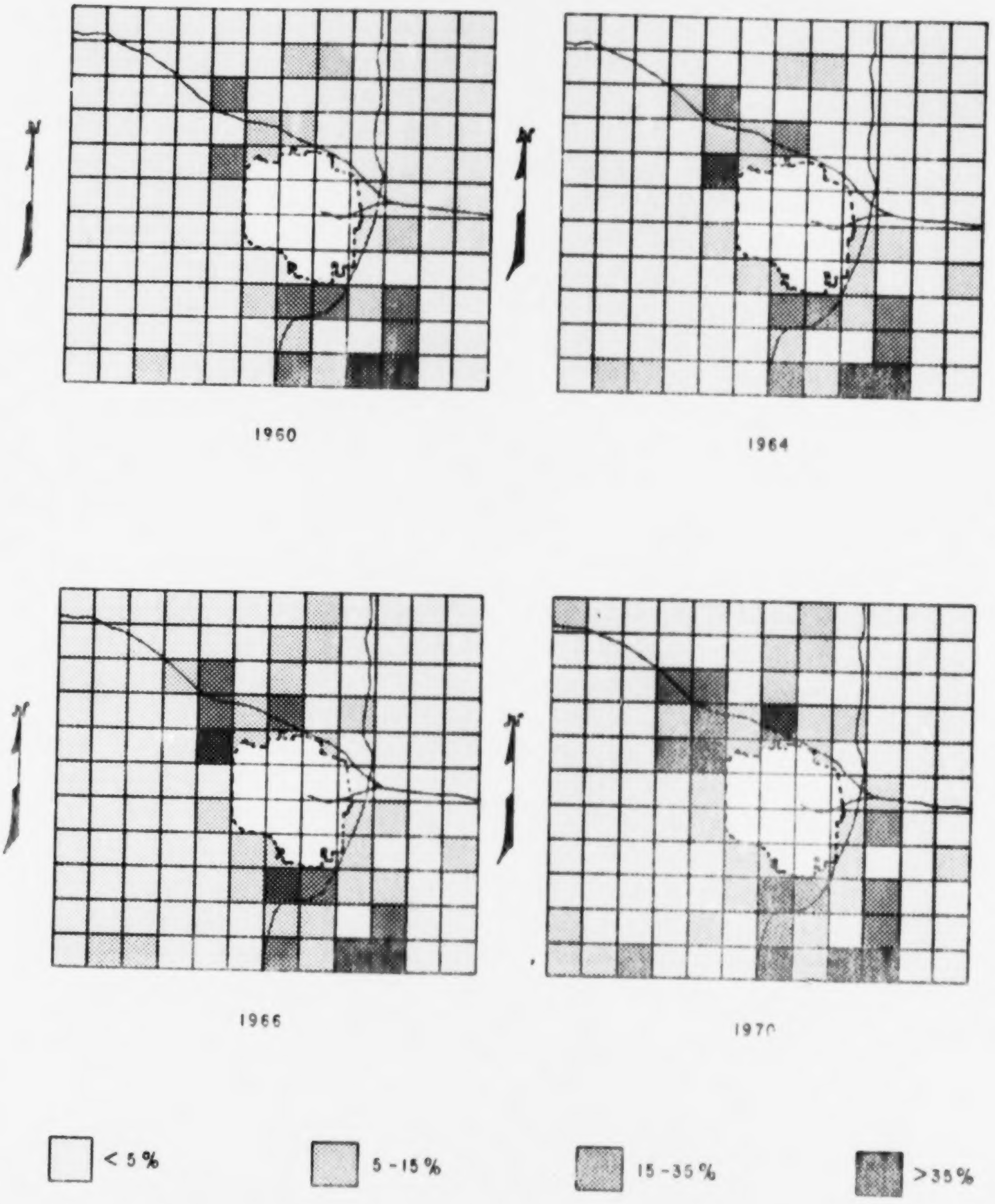

1960
1964
1966
1970
N
< 5%
5 - 15%
15 - 35%
>35%

Fig. 4.4 COMMERCIAL LAND USE


N
N
N
N
< 5%
5 - 15%
15 - 35%
> 35%

1960

1964

1966

1970

Fig. 4.5 MANUFACTURING AND WAREHOUSING LAND USE

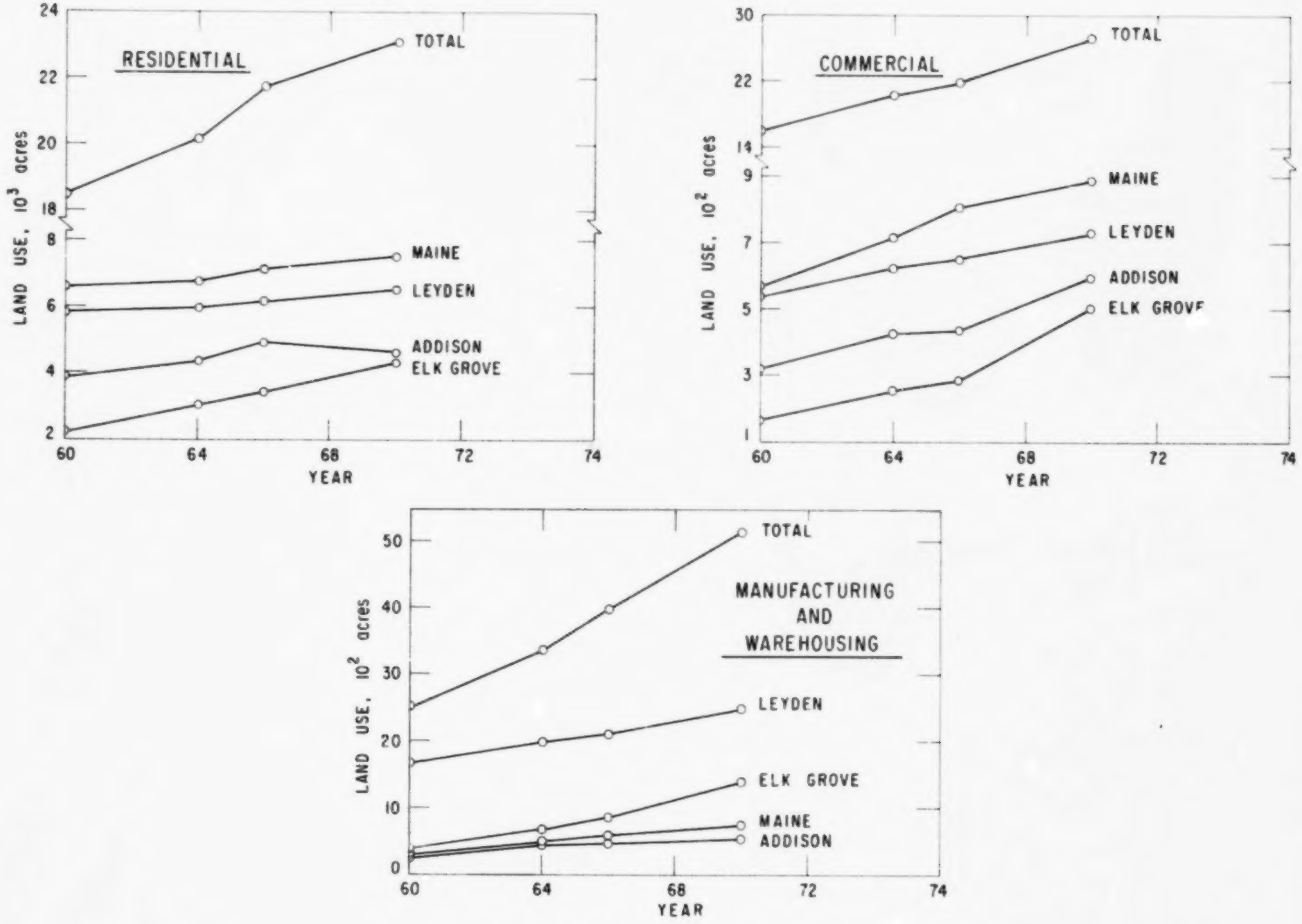


Fig. 4.6 Overall Land Use Trends in the O'Hare Study Area

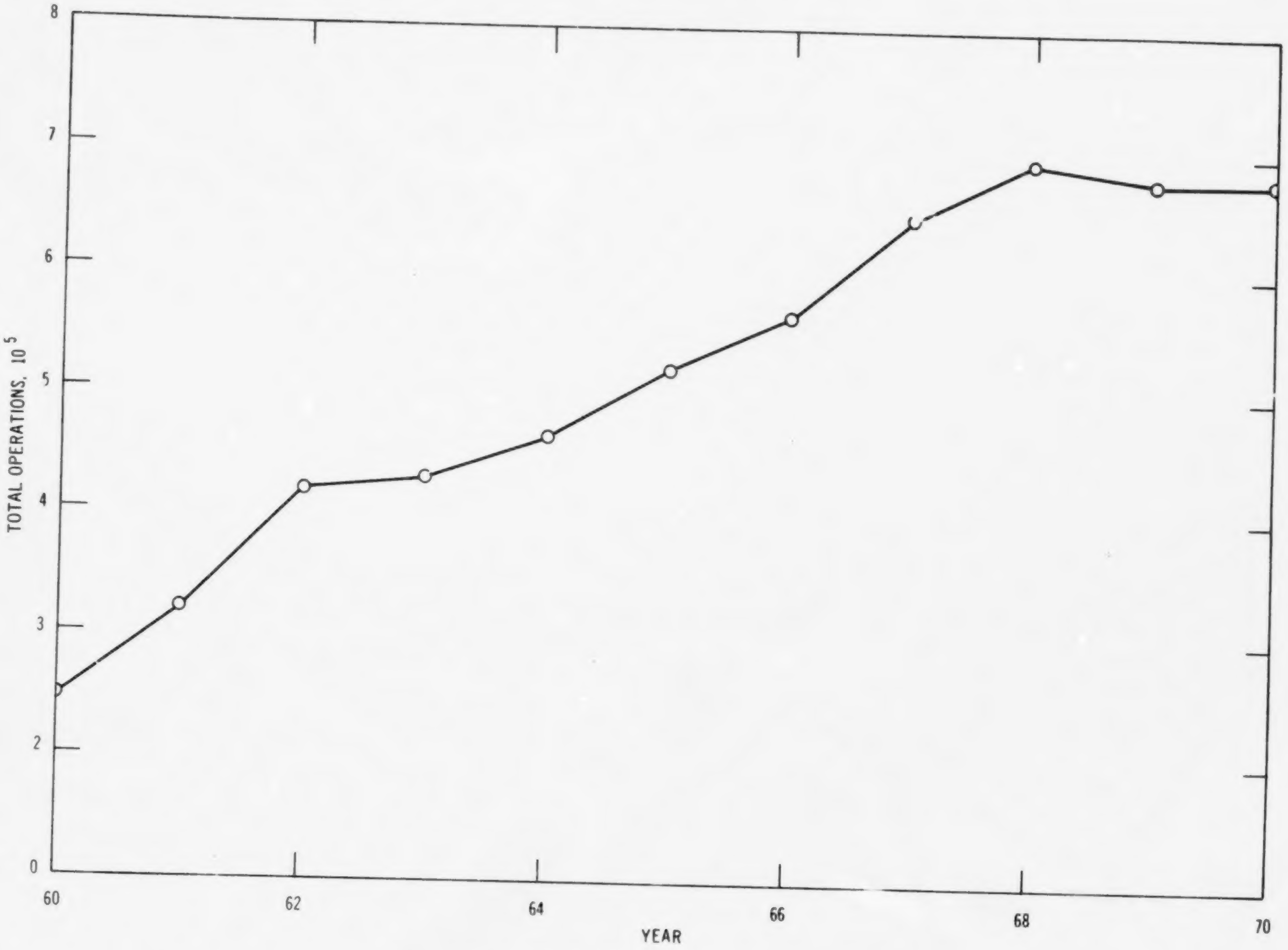


Fig. 4.7 TOTAL OPERATIONS - O'HARE AIRPORT

separate operations). The overall Cook County population increase was 7.1 per cent; however, this figure is biased by the City of Chicago decline of 5.2 per cent. It is interesting to note that the population growth was considerable in the four townships constituting the study area. From the 1960 and 1970 census of population data, the following statistics were derived:

	1970	1960	Change
Addison Township	491,882	313,459	+ 56.9%
Elk Grove Township	79,642	27,876	+185.7%
Leyden Township	99,793	81,814	+ 22 %
Maine Township	140,194	95,476	+ 46.8%
Total	391.909	246,974	+ 59 %

The large difference between the residential land use increase and the population increase for the four townships indicates that a significant portion of the land development for that area was utilized for higher density housing.

The commercial and institutional land use increased 62 per cent in the ten year period. This is comparable to the population increase as expected, since the demand for services such as additional shopping, entertainment and institutional facilities should increase proportional to the population.

The manufacturing and warehousing class experienced the largest percentage growth of the various land use categories; 104%. It is likely that a good part of this manufacturing and warehousing development was spurred by the airport and ground transportation advantages of this area. Most of the increase was due to the manufacturing while warehousing contributed a small increase to the total acreage. A critical review of the photographs indicated that most of the industry in the vicinity of the airport was medium or light industry with little of the large scale, heavy polluting installations such as power plants, steel mills, refineries, etc. Of course, a secondary effect of the large increase in manufacturing and warehousing is its effect on the ground transportation required because of an increased number of jobs and intermodal transportation.

The transportation, communications, and utilities category showed increases similar to the residential land use. This category is largely dominated by the acreage used for streets and rights of way of utilities and is therefore closely related to development of residential property.

The category covering vacant and agricultural land experienced a decline as expected since this represents the land source from which the other land use categories derive their increases. The total drain on vacant and agricultural property caused a 43.7 per cent decline in this land use category in the ten year period.

The final category; recreation, open space and water maintained a fairly constant level over the ten-year period experiencing an overall gain of 1 per cent. The total acreage of this category is approximately half that of the residential land use in 1970 and approximately equal in acreage to the commercial, institutional, manufacturing and warehousing combined for 1970.

4.3 Directional Analysis

The directional analysis was conducted in an effort to identify the directional component of land utilization in the airport area. In addition, this analysis allowed the growth along major transportation links to be more easily identified.

The study area was subdivided into eight pie-shaped zones of approximately equal size as shown in Fig. 4.8. A trend analysis was

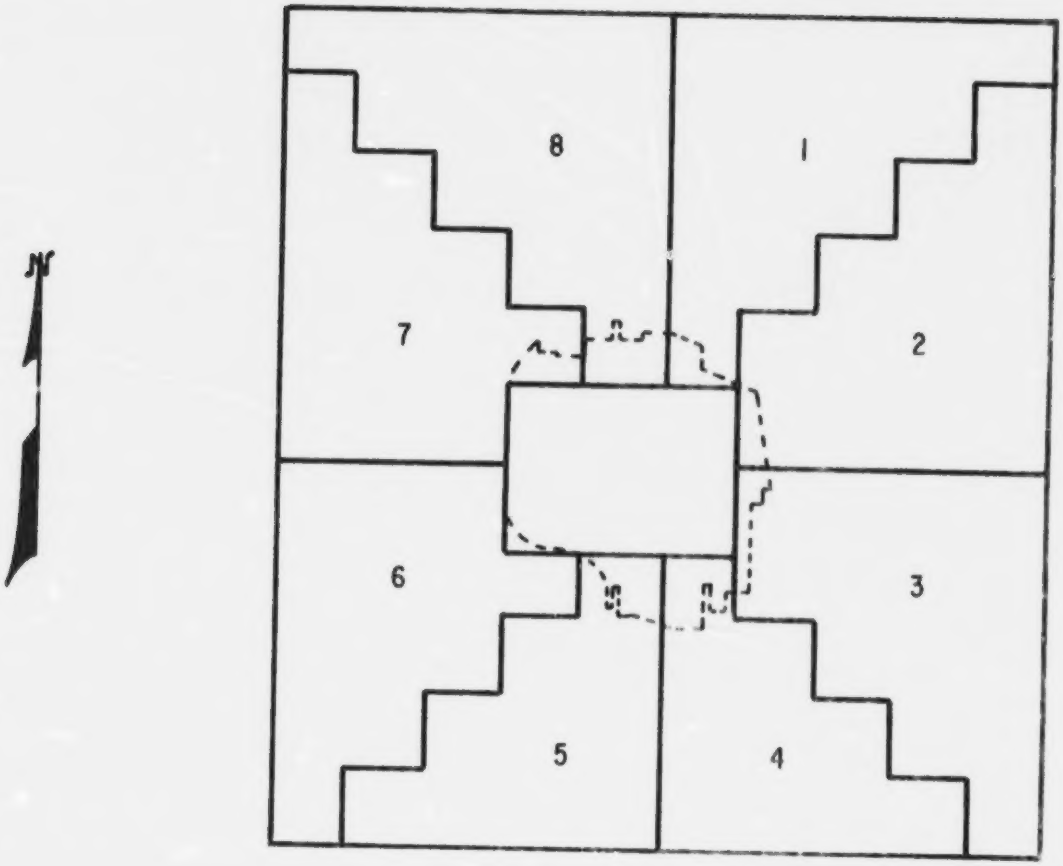


Fig. 4.8 ZONES USED FOR LAND USE/DIRECTIONAL ANALYSIS

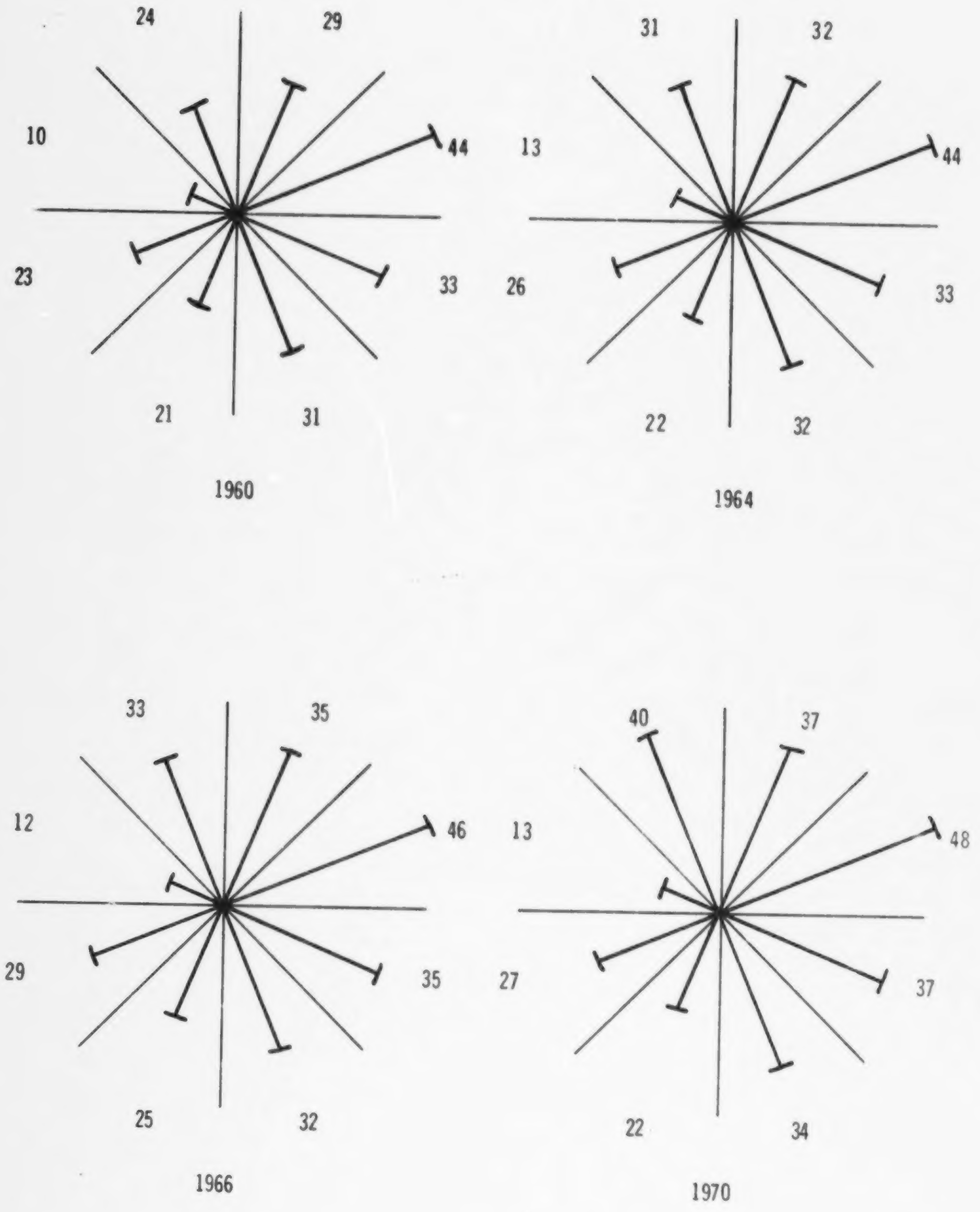
conducted for each zone and the land use per cent changes computed. The results are shown as a "land use rose" for each class and year in Figs. 4.9 - 4.11. The residential land use is considerably greater towards the east, particularly the northeast, whereas the greatest growth in terms of per cent change as occurred in zone eight which increased from 24% to 40%. This is not particularly surprising since the areas to the west of the airport are least developed.

The manufacturing and warehousing land use shows a high directional relation to the City of Chicago and also the area along the Tri-State Tollway south of the airport. However, the greatest growth in the ten-year period has occurred in the northwest sectors. Zone eight, for example, has increased almost threefold and zone seven has increased over fourfold. An extrapolation of these growth rates for manufacturing and warehousing land use in this area could lead to quite high manufacturing land use densities in the not too distant future, if not already.

The commercial and institutional land use shows directional growth similar to the residential land use. Zone eight shows the largest change over the ten-year period as did the residential growth. This is probably attributable to the transportation advantage offered by the Northwest Tollway which runs through Elk Grove Township in a southeast-northwest direction.

The Land Use/Distance Analysis

One of the basic objectives of this study is to compute and compare airport emissions with those of the surrounding land use activities which are assumed to be attendant with airport development. This portion of the analysis was aimed at identifying changes in various land use activities as a function of distance from the airport to provide a measure of local urbanization and



1960

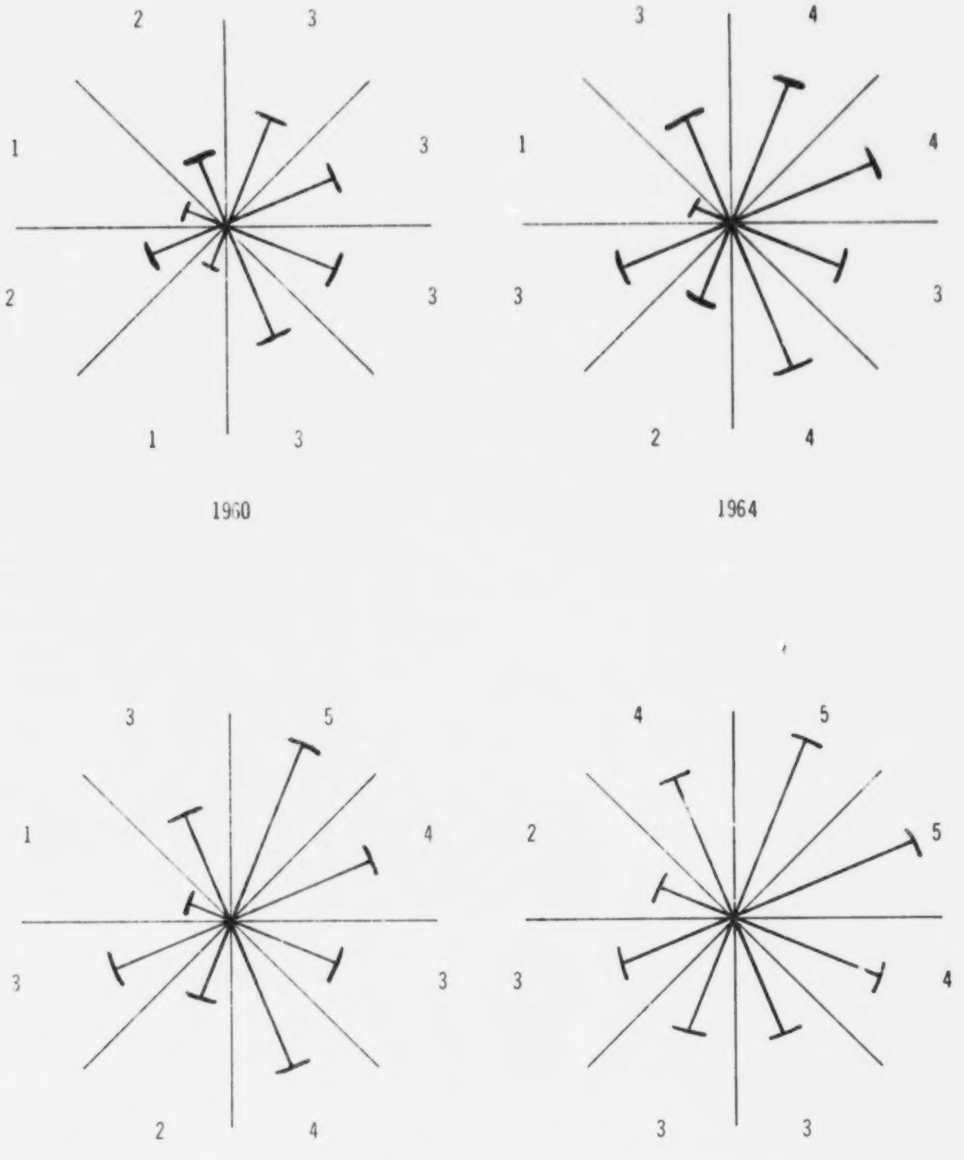
1964

1966

1970

RESIDENTIAL LAND USE PATTERNS IN VICINITY OF O'HARE AIRPORT FROM 1960 THROUGH 1970. EACH LINE SEGMENT REPRESENTS THE PERCENT OF LAND USED IN THAT SECTOR.

Fig. 4.9



1960

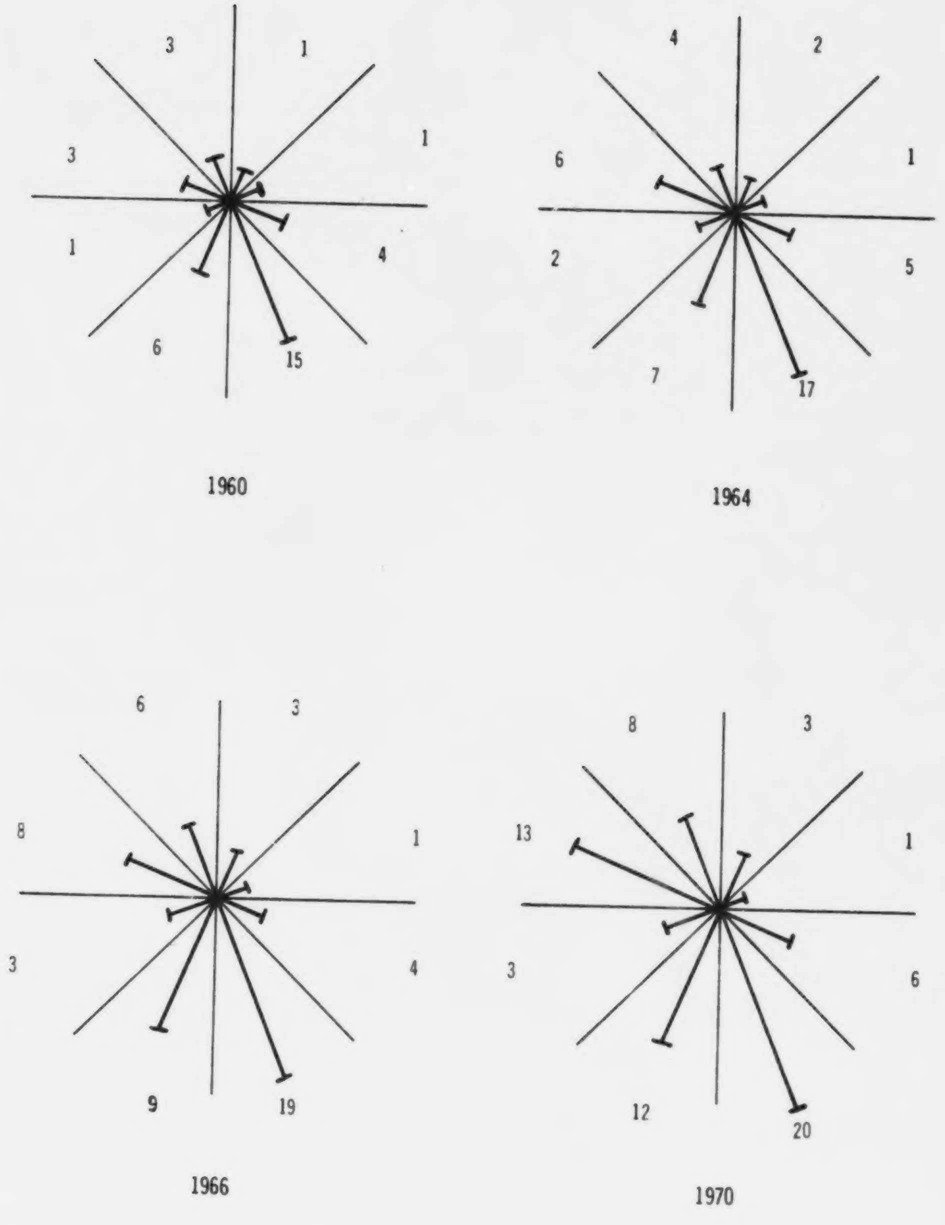
1964

1966

1970

COMMERCIAL LAND USE PATTERNS IN VICINITY OF O'HARE AIRPORT FROM 1960 THROUGH 1970. EACH LINE SEGMENT REPRESENTS THE PERCENT OF LAND USED IN THAT SECTOR.

Fig. 4.10



MANUFACTURING AND WAREHOUSING LAND USE PATTERNS IN THE VICINITY OF O'HARE AIRPORT FROM 1960 THROUGH 1970. EACH LINE SEGMENT REPRESENTS THE PERCENT OF LAND USED IN THAT SECTOR.

Fig. 4.11

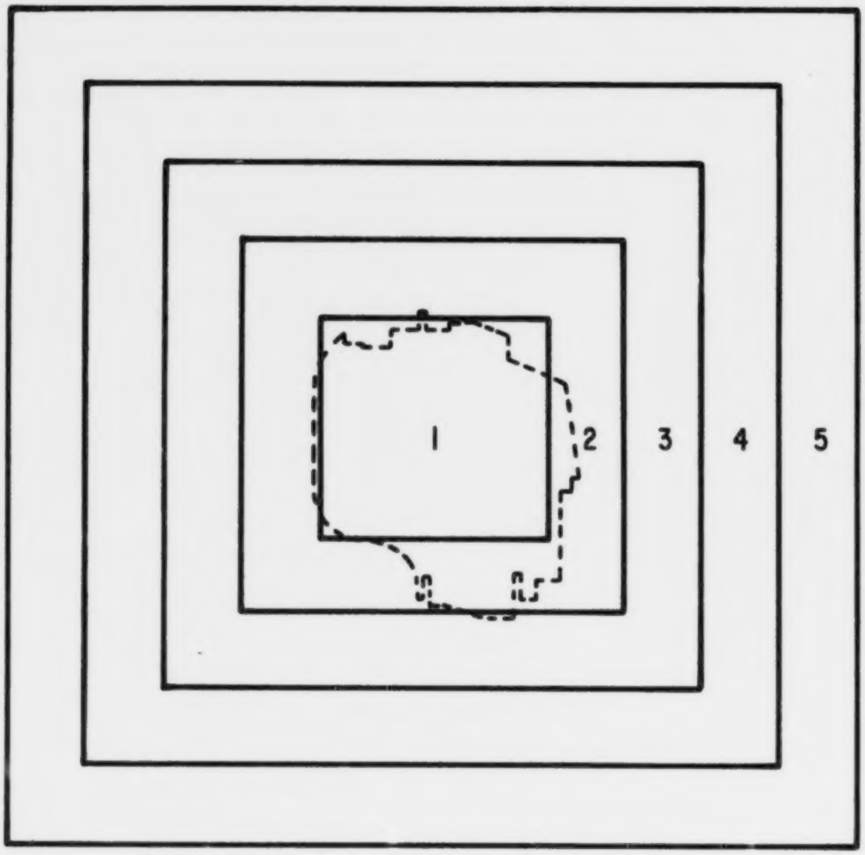


Fig. 4.12 ZONES USED FOR LAND USE/DISTANCE ANALYSIS

development in the immediate airport vicinity. The approach here was to subdivide the study area into concentric square zones at varying distances from the airport perimeter. The zones used in this analysis are shown in Figure 4.12. Each zone is one section wide or approximately one mile. Since the area of each zone is different, the per cent land use in each zone was used as the measure of change. Figure 4.13 shows the land use trends in each zone. This figure indicates increased manufacturing and warehousing development in the immediate vicinity of the airport perimeter (one-two miles). Residential and commercial activity, on the other hand, increases with increased distance from the airport.

4.4 Preparation of Land-Use-Based Emission Estimates

The evaluation of the air pollution impact of the airport and surrounding land use is logically prepared in three basic steps: 1) Isolating and quantitifying the activity, 2) transforming the activity into emission level and 3) preparing air quality estimates using a dispersion model. This section describes the intermediate phase related to converting activity levels of the land uses surrounding the airport into emission estimates on an annual basis. As stated previously, the nine categories of land use considered in this study were reviewed in terms of their contribution to atmospheric emissions, and it was concluded that the categories of significant impact were residential, commercial, institutional, manufacturing, warehousing and ground transportation. All of these categories except for a portion of the manufacturing air pollutant emissions are produced through the combustion of fuels of various types. This reduces the complexity to some degree for the estimating procedure. The problem then becomes one of converting activity levels into a fuel mix and demand and applying standardized

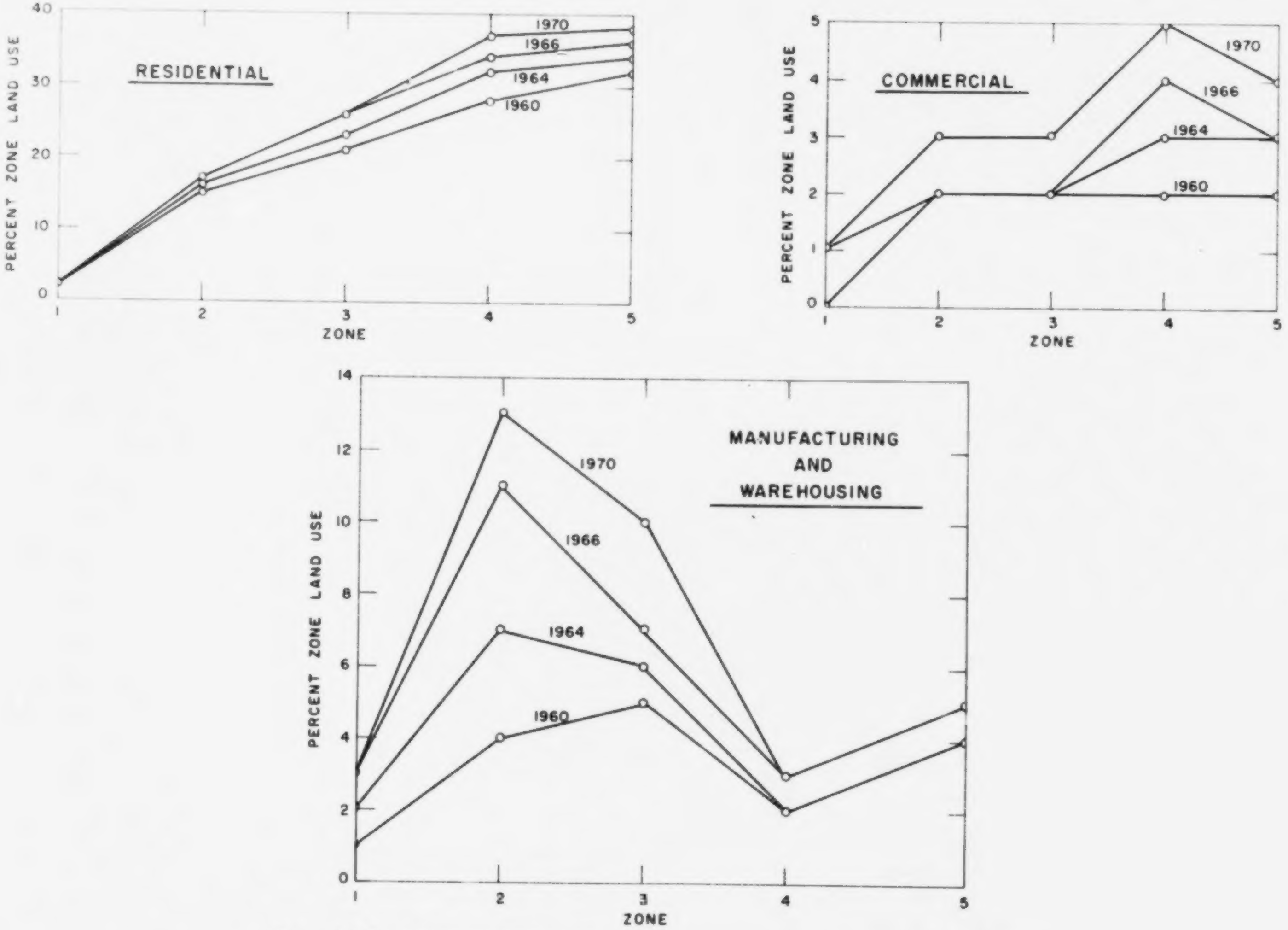


Fig. 4.13 RELATIONSHIPS OF LAND USE TO DISTANCE FROM THE AIRPORT

emission factors to these parameters. In the case of manufacturing fuel combustion emissions, correlations were made directly with land use via the Illinois Emission Inventory. This procedure will be described later. The emission estimates presented in this section are derived from annual fuel use estimates; however, shorter averaging periods could be utilized using degree day proration of fuels. This procedure has been widely utilized and produces effective correlations on a month by month basis.

4.5 Residential Emission Estimates

Residential land in the study area which is quite typical of suburban housing is composed largely of single and small-to-medium multiple dwelling buildings. The age distribution of buildings in this area is considerably skewed towards newer buildings than in-close suburbs and therefore are nearly all gas heated. For the analysis of residential emissions, it was assumed that all the emissions are due to combustion of natural gas as the space heating fuel.

The aerial survey technique which produces acreages of the various land uses was utilized as the basic input data in addition to information derived from The Peoples Gas, Light and Coke Company and the City of Chicago, Department of Environmental Control.

The correlation of fuel use as a function of building size for buildings in the Chicago Metropolitan area is compiled by the Peoples Gas Company utilizing the entire City of Chicago as the data base. This information, derived from actual fuel use information, has been verified through the use of theoretical heating load estimates and design ambient temperatures. A comparison of these two methods correlates extremely well. For the purposes of this analysis, the actual Peoples Gas Company data was utilized. A summary of residential fuel use information is presented in the table below:

QUANTITIES OF GAS, OIL AND COAL USED YEARLY
PER DWELLING UNIT BY DIFFERENT SIZED RESIDENTIAL BUILDINGS

Number of Apartments/Building	Gas (Cubic Feet)	Oil Gallons	Coal (Tons)
1	140,000 (.80)	1,068 (.75)	6.48 (.64)
2&3	126,733 (.80)	965 (.75)	5.86 (.64)
4-7	109,840 (.80)	837 (.75)	4.78 (.68)
8-19	95,000 (.80)	726 (.75)	4.14 (.68)
20-59	80,000 (.80)	610 (.75)	3.16 (.75)
60+	72,000 (.80)	549 (.75)	2.84 (.75)

Figures in parenthesis indicate burning efficiencies of the fuel burning equipment.

The problem of estimating emissions is now reduced to estimating the density of dwelling units (DU) and combining this with the acreage figures from the aerial survey and multiplying by the fuel use estimates given above. Three categories of residential building densities were defined, light, medium and heavy. These categories were established by reviewing the aerial photos containing residential property in the study area and partitioning this information into the three categories with approximately equal acreages for each. Based on this sampling process, the following categories were defined:

High density	6.2 DU per acre
Medium density	3.7 DU per acre
Low density	1.6 DU per acre

These values represent the mean in each of the three categories. It is important to note that single dwelling unit buildings or individual houses represent the overwhelming majority of the total building stock.

The residential land use in each of the individual sections of the entire study area were then appropriately categorized into one of the three classes. This information, in combination with the densities, provides a number of dwelling units per section for the study area. Using the fuel demand figures provided above, emissions are then calculated (Table 4.2) for the five primary pollutants (particulates, SO_2, CO, HC, NO_x). A sample calculation is shown below for particulate emissions from high density residential land use. Emission factors are from McGraw and Duprey.[28]

Natural Gas Consumption =

$$6.2 \frac{DU}{acre} \times 1.4 \times 10^5 \text{ ft}^3/\text{DU/yr} = .868 \times 10^6 \text{ ft}^3/\text{acre/yr}$$

Particulate Emissions =

$$(19 \text{ lb}/10^6 \text{ ft}^3)\ (.686 \times 10^6 \text{ ft}^3/\text{acre/yr}) = 16.5 \text{ lb/acre/yr}$$

4.6 Commercial and Institutional Emission Estimates

The procedure for estimating emissions from commercial and institutional land use is quite similar to that for residential. The problem is basically one of transforming commercial acreage into emissions using observed densities of commercial activity (square feet of building space per acre) and fuel demand and mix information. The density of commercial and institutional buildings was derived again by a sampling of sections in the study area. This process involves isolating typical commercial land use plots on the aerial photographs and measuring the ratio of building floor space to acreage of land use. The measurements of floor space was accomplished by the use of a planimeter and the observed number of stories of building height. The land area was derived from the dot count or the use of a planimeter. An error analysis comparing these two methods, which is given in Appendix A,

TABLE 4.2 EMISSION DENSITIES FROM RESIDENTIAL LAND USE IN THE VICINITY OF O'HARE AIRPORT

Dwelling Unit Density	Emissions (lb/acre/yr)				
	Particulates	SO_2	CO	HC	NO_x
High (6.2 DU/acre)	16.5	.52	17.4	6.9	43.4
Medium (3.7 DU/acre)	9.8	.31	10.4	4.1	25.9
Low (1.6 DU/acre)	4.3	.13	4.5	1.8	11.2

shows that the two methods are quite comparable. An analysis of commercial and institutional building density indicated that an essentially constant ratio of building size to acreage was observed. This is shown by the scatter diagram in Fig. 4.14. This figure indicates that the ratio of building space to land area is fairly independent of acreage. This probably indicates that commercial property is fully utilized for buildings to the extent that sufficient parking, landscaping, utility right of way and other miscellaneous land requirements are also allotted. In addition, many communities require minimum parking space as part of their zoning regulations. The spurious points on the scatter diagram probably represent commercial property which has not yet been developed to the full extent and the ratio would be much less than average or, on the other hand, an intensive utilization of commercial property possibly with tall buildings. The average value taken from this analysis was 7,536 square feet per acre. This figure was then applied to the commercial land use produced by the aerial photographic technique and a total quantity of commercial and institutional building space results.

Computation of Energy Requirements for Commercial/Institutional Land Use

The primary source of data for the analysis of fuel use required by commercial and institutional buildings is an inventory compiled and updated by the Chicago Department of Environmental Control (DEC) including historical information on over 6,000 buildings in the City of Chicago. In addition, the fuel mix was estimated from data prepared by the Peoples Gas, Light and Coke Company. Their data indicated a breakdown of 85% natural gas and 15% oil to satisfy heating demands. Coal use was assumed to be neglible for the same reasons assumed in the residential analysis, that is, that the

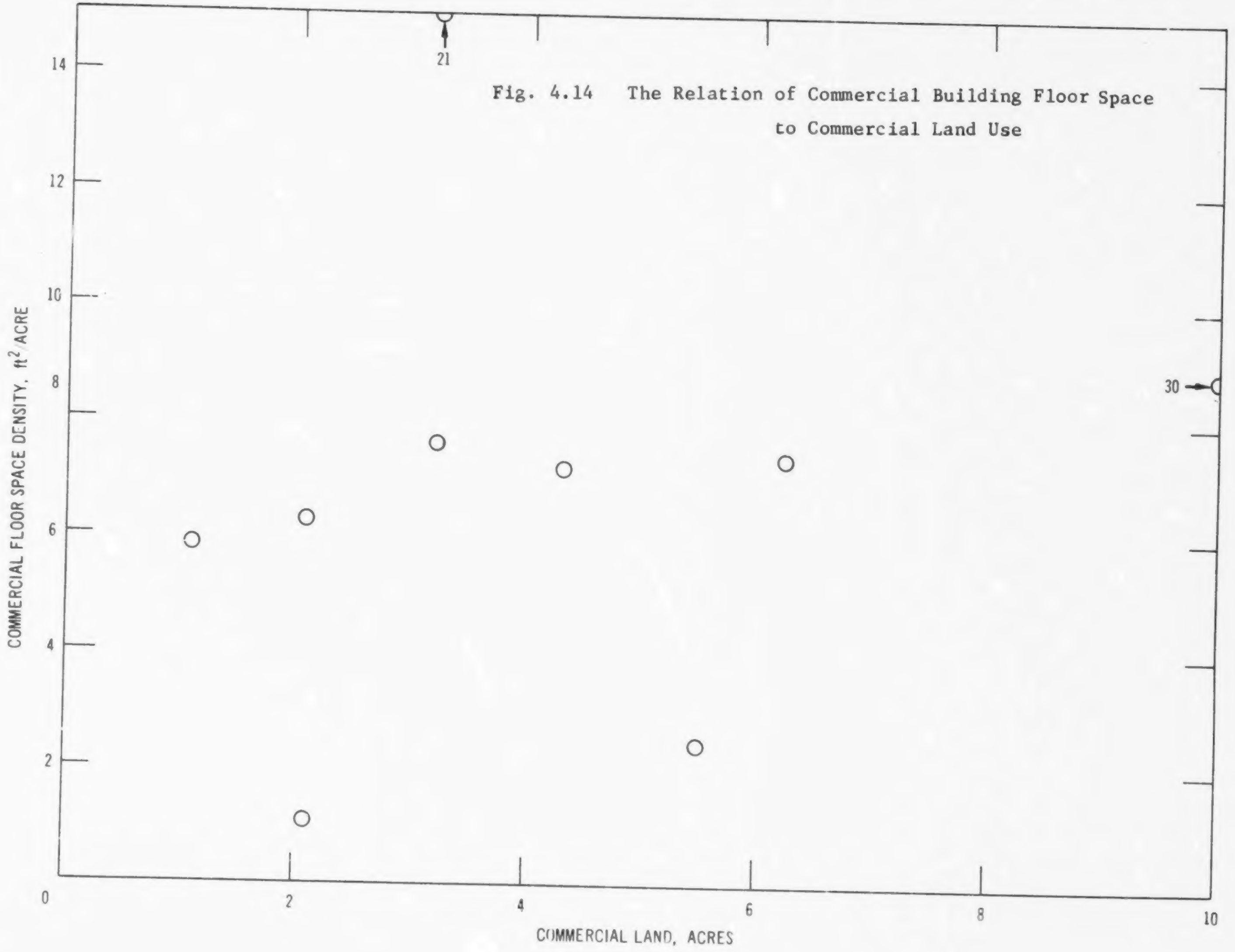


Fig. 4.14 The Relation of Commercial Building Floor Space to Commercial Land Use

buildings in the O'Hare study area are much newer than in Chicago and are not likely to utilize coal as a space heating fuel.

The computerized inventory of commercial and institutional buildings from the Chicago DEC was analyzed to prepare a frequency distribution of building size. The results of this analysis are shown in Fig. 4.15. This figure indicates that an extremely large proportion (approximately 87%) of the commercial and institutional buildings are in a size category less than 50,000 square feet. The average energy demand in each of these building size categories was also computed with this data base. These averages were computed in terms of energy required (10^6 Btu per 1000 square feet). The distribution of buildings was divided into two categories, less than 50,000 and greater than 50,000 square feet. The average heating requirement per square foot was computed for each of these two categories ($.63 \times 10^6$ Btu/1000 ft.^{2}/day for buildings less than 50,000 ft.^{2} and $.29 \times 10^6$ Btu/1000 ft.^{2}/day for others). These figures were then combined to produce an expected value (E_w) for the estimation of overall commercial energy requirements. This is illustrated by the following formulation:

$$\text{Expected Energy Demand} = f_1 E_1 + f_2 E_2$$

$$= [(.87)(.63 \times 10^6) + (.13)(.29 \times 10^6)]\ 365$$

$$= 208 \times 10^6 \text{ Btu/1000 ft./year}$$

E = energy demand f = fraction of buildings

Then:

$$(208 \times 10^6 \ \frac{\text{Btu}}{1000 \text{ ft.}^2})\ (7536 \text{ ft}^2\text{/acre}) = 1.57 \times 10^9 \text{ Btu/acre/yr.}$$

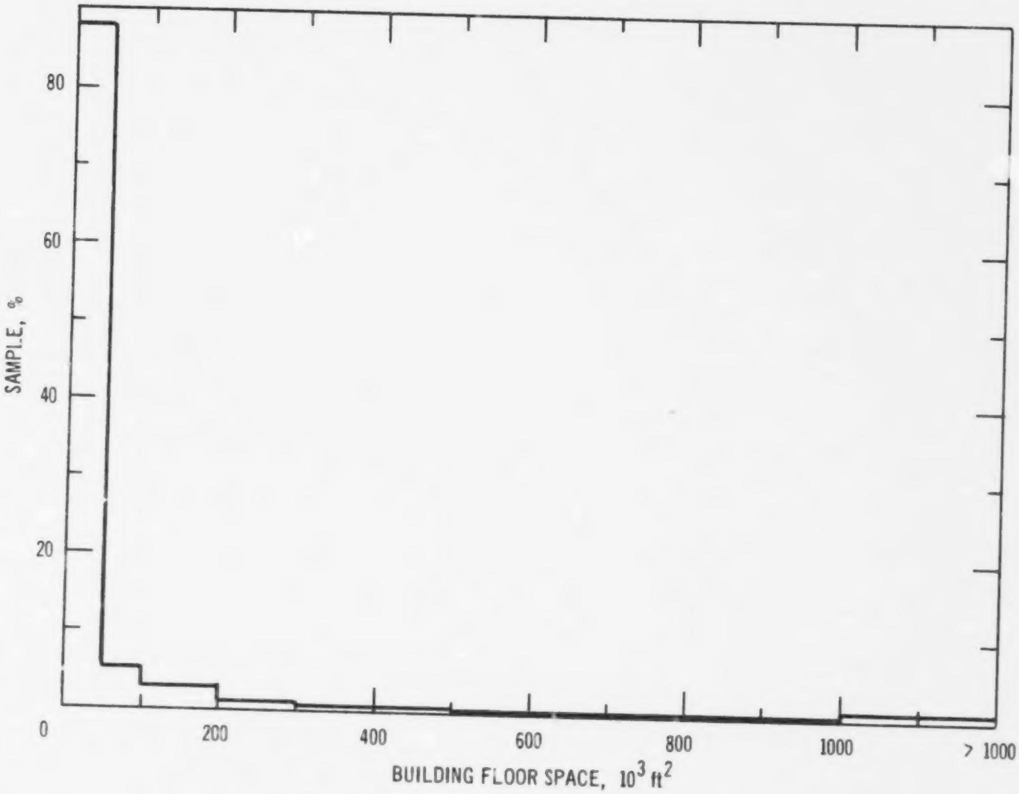


Fig. 4.15 COMMERCIAL/INSTITUTIONAL BUILDING SIZE DISTRIBUTION IN CHICAGO

The combination of these two factors then provides, on a section-by-section basis, the energy requirements for commercial and institutional land use. Emission factors based on the previously mentioned fuel mix can now be applied to compute the total commercial/institutional emissions. These are presented in the following table:

	TSP	SO_2	CO	HC	NO_x
Emissions lb./acre/year	53.3	119	26.7	15.7	234

Estimation of Manufacturing and Warehousing Emissions

The land-use based emission estimates for manufacturing and warehousing are based on an analysis of the State of Illinois Emission Inventory which was collected on a statewide basis in 1970. The design of the emission inventory for Illinois was prepared by the Argonne Center for Environmental Studies and the data included information relating to land use, acreages, and employment. Fortunately, a large number of the industries surveyed submitted this data. In addition, manufacturing type information according to standard industrial classification (SIC) was acquired. This information was utilized as the data base for estimating emission density factors on an SIC basis. The inventory was initially reduced to cover only the Chicago Metropolitan Area Quality Control Region to include sources typical of the Northeast Illinois Area. The inventory was also partitioned according to fuel combustion and process emissions.

A detailed survey of the aerial photographs in the O'Hare vicinity indicated that industries normally associated with large process emissions were not present. The industry in the O'Hare vicinity was typically medium sized with some heavy industries such as food and kindred products. Furthermore, industries which would emit process emissions of HC, CO, NO_x (those related to an airport area analysis) were also absent from the study area. Therefore, the fuel combustion portion of the inventory was used as the analytical basis for estimating density factors.

For each SIC class, the mean emission density was computed in tons/acre/day from the Illinois inventory. The results of this analysis are shown in Table 4.3. A more detailed statistical analysis of the relation between emissions and land use is given in Kennedy, et al.[37] For purposes of estimating emissions and demonstrating the procedure, the overall mean estimator for each pollutant was used to compute industrial emissions for this study. These values were then multiplied by the manufacturing and warehousing acreages in each of the sections to produce the manufacturing/warehousing emissions.

Table 4.3

Fuel Combustion Emission Densities for Various Two Digit Standard Industrial Classifications

(Tons/Acre/Year)

Two Digit Standard Industrial Classification (SIC)	Pollutant				
	SO_2	Particulates	CO	HC	NO_x
20	2.38	2.87	.23	.14	1.05
21	-	-	-	-	-
22	-	.05	-	-	-
23	-	.02	-	-	-
24	.40	.02	.01	.02	.21
25	.57	.04	.04	.05	.47
26	5.29	4.96	.44	.27	2.08
27	.02	.05	.40	.40	3.2
28	2.02	1.3	.11	.09	.89
29	5.48	.507	.12	.20	2.68
30	.26	.03	.03	.03	.31
32	4.82	5.6	.54	.32	2.16
33	2.77	2.6	.43	.37	3.13
34	1.0	.18	.21	.22	1.92
35	2.60	.51	.06	.08	1.01
36	1.94	.22	.07	.10	1.14
37	3.54	2.51	.15	.13	1.30
38	3.02	.16	.02	.07	1.13
39	.43	.26	.07	.06	.48
Mean	2.62	1.57	.21	.180	1.63

4.7 Ground Transportation Emissions

In cooperation with the Chicago Area Transportation Study (CATS), Argonne has constructed a vehicular emissions computer simulation utilizing output from the CATS Model and the latest federal EPA emission factors (see Table 4.4). This computerized system consists of two main segments. First, an emission factor section which has the capability of producing emission factors based upon variations of several parameters such as localized age distribution, space-dependent, vehicle-mile, and speed estimates, and the computation of the "cold start" emission phenomenon as described by General Motors.[38] This phenomenon is due to the relatively large emissions which occur during the initial 2 to 3 minutes of operation of a cold automobile engine.

The second segment of the system is an emissions computation segment which utilizes the appropriate emission factors from the first segment in combination with the output of the CATS simulation model and produces emissions on a gridded basis over the entire region that can be used in a diffusion model or to produce emission density maps.

The traffic distribution data for private vehicles was supplied by the CATS (Chicago Area Transportation Study) group traffic simulation model. This model calculates the transportation activity in the 8-county Northeastern Illinois region and distributes the traffic volumes over a highway network.

The CATS planning activities utilize a traffic zone system. Over 1700 zones are used to simulate the transportation activities in the study area. These zones vary in size from a quarter square mile in the central business district to 36 square miles in the outlying counties (see Fig. 4.16).

Table 4.4 Emission Factors* (Grams/Veh-mile)

	CO			HC					NO_x	
	Urban	Rural	Cold Start	Crank-case	Evapor-ation	Exhaust		Cold Start	Urban	Rural
						Urban	Rural			
1970	56.5	29.7	216.8	1.22	2.93	9.15	5.55	13.7	9.49	9.72
1975	23.6	12.6	161.7	.32	1.26	3.78	2.32	13.6	7.31	7.48
1980	6.80	3.89	77.4	.06	.44	1.14	.73	7.1	3.88	3.94

*These are "weighted" factors based on 6 vehicle classes using Cook County age distribution and federal EPA deterioration and emission data.

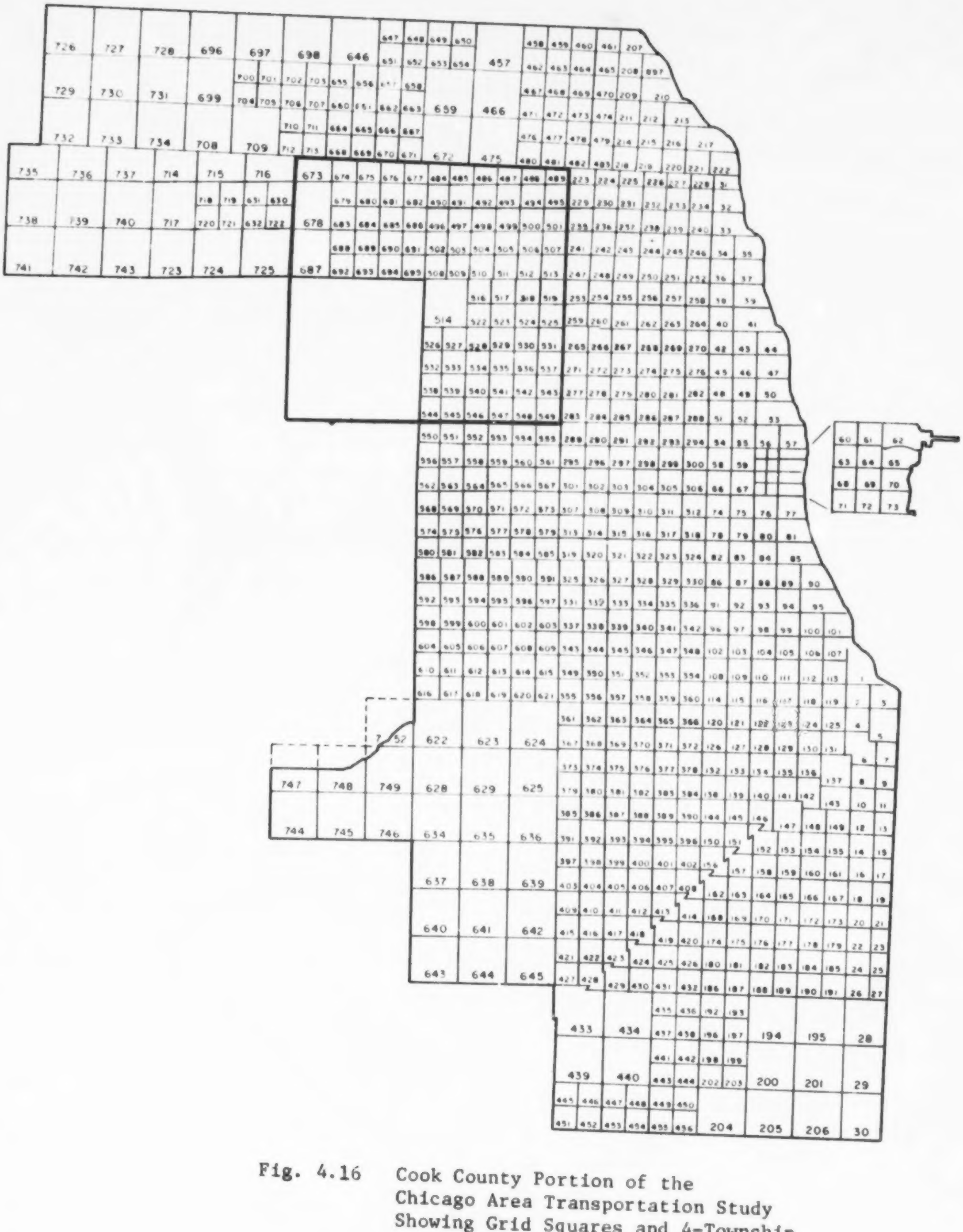


Fig. 4.16 Cook County Portion of the Chicago Area Transportation Study Showing Grid Squares and 4-Township Study Area.

An intervening opportunity model is used by CATS to generate the transportation activity levels between zones in the regions. These activity levels are generated in the form of trips between traffic zones in the region. The intervening opportunity model determines the number of trips for different reasons in a zone and then determines the destination of these trips, using probability distributions characteristic of the opportunities in the zones.

After the number of interzonal trips has been determined by the intervening opportunity trip generation model, modal split data (split between public and private transit) is used to determine the number of people using private transportation. Each interzonal trip can use several paths and therefore a capacity constraint distribution model is used to distribute the trips over possible roadways. The total vehicle miles in each zone are summed from the trips and links occurring in that zone. The average speed on each roadway is calculated from a volume/capacity relationship. The output from the CATS simulation which is used by the emission inventory includes trip origin (to compute cold start emissions), roadway speed, and roadway vehicle miles (all on a zone basis).

For the purposes of computing vehicle emissions in the airport vicinity, the local registration data was utilized (Table 4.5). This data was derived from the Illinois Secretary of State's Office of Vehicle Registration. It has been indicated that the age distribution for automobiles in the Chicago area is significantly different from that on a national basis for which emission factors presented in the latest federal EPA publication[28] indicate. The Argonne model utilizes the local age distribution for Cook County in conjunction with a set of "primitive" emission factors supplied by the federal EPA. These emission factors do not include the national age

Table 4.5

Age Distribution of Vehicles Registered in Cook County Illinois as of July 1, 1970

Model Year		Number of Vehicles	Percent of Total
1970		232345	11.6
1969		288479	14.4
1968		261092	13.1
1967		224673	11.2
1966		217727	10.9
1965		209143	10.5
1964		162912	8.2
1963		133992	6.7
1962		104548	5.2
1961		59150	3.0
1960		45933	2.3
1959		20121	1.1
1958		8453	.42
1957		9303	.47
1956		5577	.28
1955		4816	.24
Pre 1955		10012	.50
	Total	1,998,281	100%

weighting. The Argonne model also produces projected emissions through 1980.

The different vehicle types have been handled by creating 5 vehicle-size categories and producing an emission factor for each of the 5 categories, ranging from Class 1 which is light duty vehicles or cars to Class 5 which is heavy duty trucks of the Diesel type. The distribution of vehicle sizes was also derived from the Illinois Secretary of State's Office of Registration data for 1970.

5. EMISSION DISPLAY

Section 3 described the methodology used to estimate airport activity and the various related emission factors which could be used for air pollutant emission calculations. Section 4 provided the same information needed to estimate land use emissions. There are a multitude of ways in which the emissions from these sources can be presented; this section will discuss some recommended procedures.

In choosing the appropriate forms of displaying the information, the ultimate goal of incorporating these results into a regional air quality management program must be kept in mind. Thus, while data on actual emission rates are important, information on emission trends, relative order of magnitude of emission sources, emission densities, and effects of alternatives are, perhaps, even more important. This type of presentation will enable planners to glean the maximum amount of useful information with a minimum amount of searching through the data. Since presentation of the data in this format often requires little additional information other than what has already been described in Section 3 and 4, the utility of this approach becomes even more desirable.

Information presentation to improve the air pollution analysis of the Environmental Impact Statement[1] for the St. Louis airport will be discussed as an example of the application of the emission display techniques.

5.1 Airport Emissions

As previously shown on Fig. 3.1, the air pollutant emissions for the airport come from six major sources. They are the following:

- Airport
- Ground Service Vehicles
- Fuel Storage and Handling

To make a comparison with an existing airport, the emissions per aircraft LTO and emissions per enplaned passenger are calculated for O'Hare airport and presented on Table 5.3.

5.1.2 Ground Service Vehicles

In evaluating the contribution of ground service vehicles to the overall airport air pollutant emission load, two considerations must be dealt with. The first is the order of magnitude of the ground support equipment emissions relative to other sources; the second is the effectiveness of emission control in reducing this contribution.

Many studies of airport air pollution have treated the ground support equipment as a negligible source of emissions and have not included their contribution to the total emissions. This study, as well as that undertaken for O'Hare Airport[12], indicates that this is not the case. Figure 5.5 displays the ground service vehicle emissions for the St. Louis airport using the Speas forecast. The two sets of curves present the calculations for the assumption that ground support equipment, as off-road vehicles, will not be subject to emission controls, and for the assumption that these vehicles will be subject to the 1975-76 federal automotive emission standards. These curves are designated uncontrolled and controlled, respectively.

The figure indicates that for the case of St. Louis, the uncontrolled emissions amount to about 1905 tons of CO, 425 tons of hydrocarbons, 111 tons of NO_x, and 4 tons of particulates in 1990. This means that the CO and HC emissions from ground service vehicles approach 30% of the aircraft emissions which is certainly not a negligible quantity. The NO_x and particulate emissions are on the order of 2% of the aircraft emissions. These results, along with similar conclusions for O'Hare, point to the fact that ground service

- Engine Test and Maintenance Facilities
- Heating and Air Conditioning Plant
- Access Traffic

Each will be discussed separately in the following sections and a summary display of airport emissions will be presented in Section 5.1.7.

5.1.1 Aircraft Emissions

The primary concerns in aircraft emissions are the actual emission rates, the source of emissions by aircraft mix and mode of operation, and the trends in aircraft emissions. The data presentation format should reflect these considerations.

Emission Rates

The rate of air pollutant emissions from aircraft is obtained by using the calculation procedure recommended in Section 3.3 to apply the emission factors of 3.2 to the activity projections of 3.1. The result is displayed as a plot of emissions versus time for the forecast period. Figure 5.1. shows this information as calculated for the three forecasts for the St. Louis airport. This graph shows the actual rate of emissions from the projected aircraft activity level and mix, and can be used as an input to a dispersion model to estimate air quality.

As the figure shows for all forecasts, the carbon monoxide and nitrogen oxide emissions are projected to increase sharply, the hydrocarbon emissions are expected to increase at a slower rate and the particulate emissions are expected to remain essentially constant.

For the Speas forecast in the 1975-2000 period, the CO emissions increase by 322%, and the NO_x by 382%, the HC emissions increase by 195%, and the particulate emissions increase by 7%. The aircraft activity level in this period has increased by 86%.

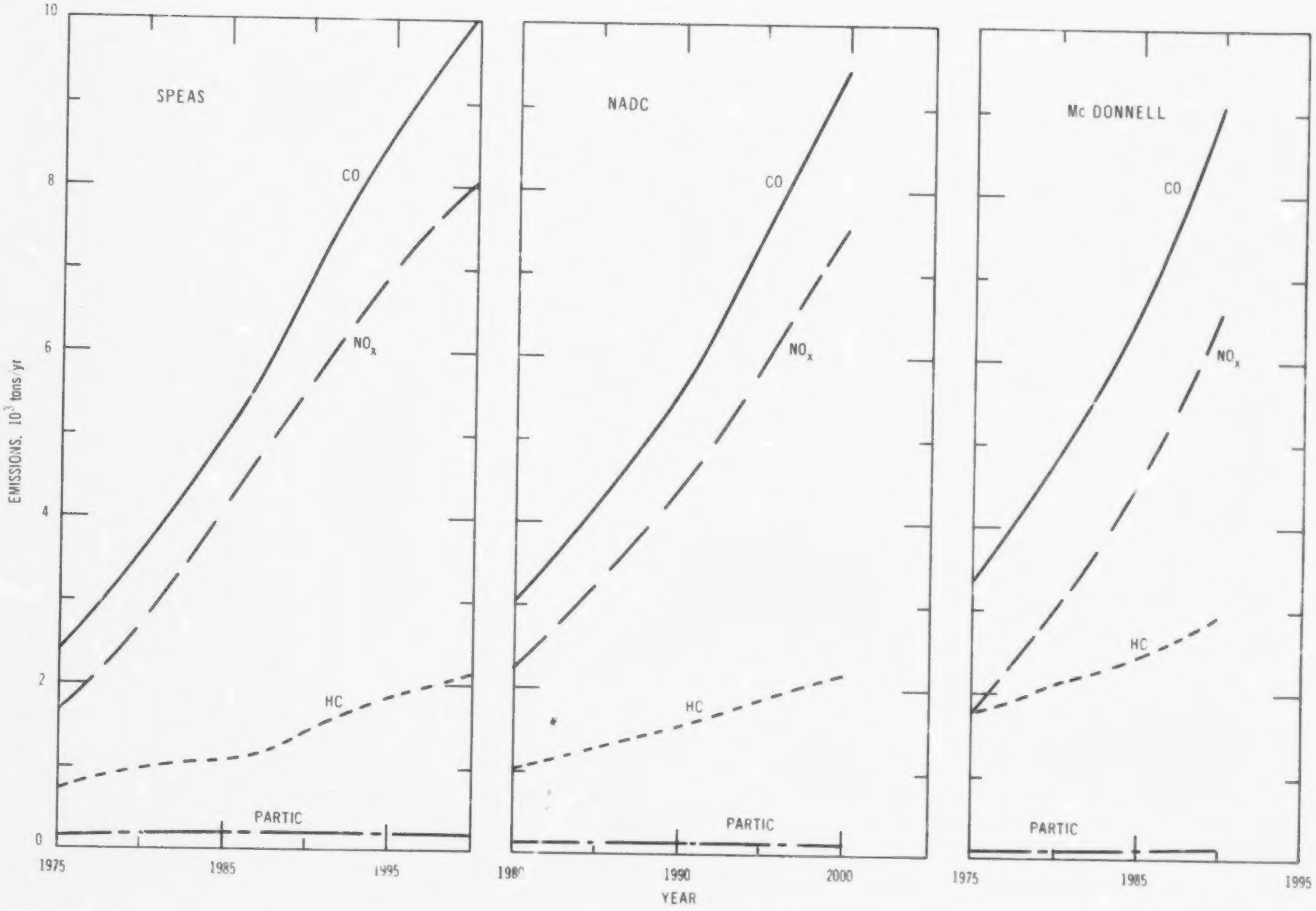


Fig. 5.1 Annual Aircraft Emissions
St. Louis Airport

The deficiency in presenting emission rates alone can be seen by trying to utilize the curves of Fig. 5.1 to estimate air quality impacts of an airport and to plan for emission controls. The reason for the differences in the growth rates of the four pollutant loads cannot be readily discerned; neither can the major contributors to the emission be singled out.

As discussed in Section 2, the Environmental Impact Statement for the St. Louis airport does not include an extensive analysis of the air pollution impact. The Statement should have included at least a curve comparable to Fig. 5.1. The aircraft emissions are presented for 1990 only; essentially only one point on Fig. 5.1 has been calculated. (By way of comparison, the Impact Statement projects an aircraft emission rate in 1990 of 9,490 tons/year of CO, 4,015 tons/year of organics, 4,745 tons/year of NO_2, and 2,920 tons/year of particulates. With the exception of particulates, the rates are comparable to what is shown on Fig. 5.1. The particulate rate as projected by the Impact Statement differs by an order of magnitude. It is not possible to resolve this discrepancy since no information is presented on the calculation procedure used.)

Emissions by Aircraft Mix

An additional piece of information needed to fully understand the curves on Fig.5.1 is a breakdown of the emission contribution by aircraft class.

A qualitative feel for the factors behind the differences in the emission growth rate of each pollutant type can by had by looking at the aircraft emission factors on Table 3.33 and by noting that all of the forecasts call for a gradual phasing out of the B-707/DC-8 and the B-727/DC-9 aircraft which utilize JT3D and JT8D engines respectively. These aircraft are to be replaced by B-747 and DC-10/L1011 aircraft which utilize the JT9D. Table 3.33 shows that the JT9D has a CO emission rate that is comparable to the higher-CO-emitting JT3D, an HC emission rate comparable to the lower-HC-emitting JT8D, an NO_x emission rate that is substantially greater than either the JT3D or the JT8D, and a particulate emission rate that is substantially lower than either the JT3D or the JT8D. This means that in the course of the forecast period airplanes are being utilized which have on the average higher CO and NO_x emissions, only slightly higher HC emissions and lower particulate emissions. This can be illustrated graphically by plotting the fraction of emissions being contributed by each aircraft class. Figure 5.2 shows the mix as forecast by Speas (from Table 3.10) and the relative contributions of each aircraft class to the emission rate. It can be seen that the Class AA aircraft (747/DC10/L1011) contribute more to the CO and NO_x than the relative magnitude of their activity, somewhat more to the HC, and substantially less to the particulates. Classes C, D and E (small business aircraft and general aviation) are only small contributors to the emission load even though their activity is about 13% of the total activity.

The use of Fig. 5.2 in tandem with Fig. 5.1 thus demonstrates several facts not readily discernable from Fig. 5.1 alone. Over the course of the forecast period (1975-2000), any attempt to reduce aircraft CO and NO_x emissions for the St. Louis region should concentrate on the Class AA aircraft. These airplanes contribute more to the overall CO and NO_x emission load than their numbers would warrant. Reductions in their CO and NO_x emissions would provide more than a proportional reduction in total CO and NO_x emissions. For hydrocarbons the same conclusion can be reached but the difference between Class AA activity and contribution to HC emission load is not as pronounced. In addition,

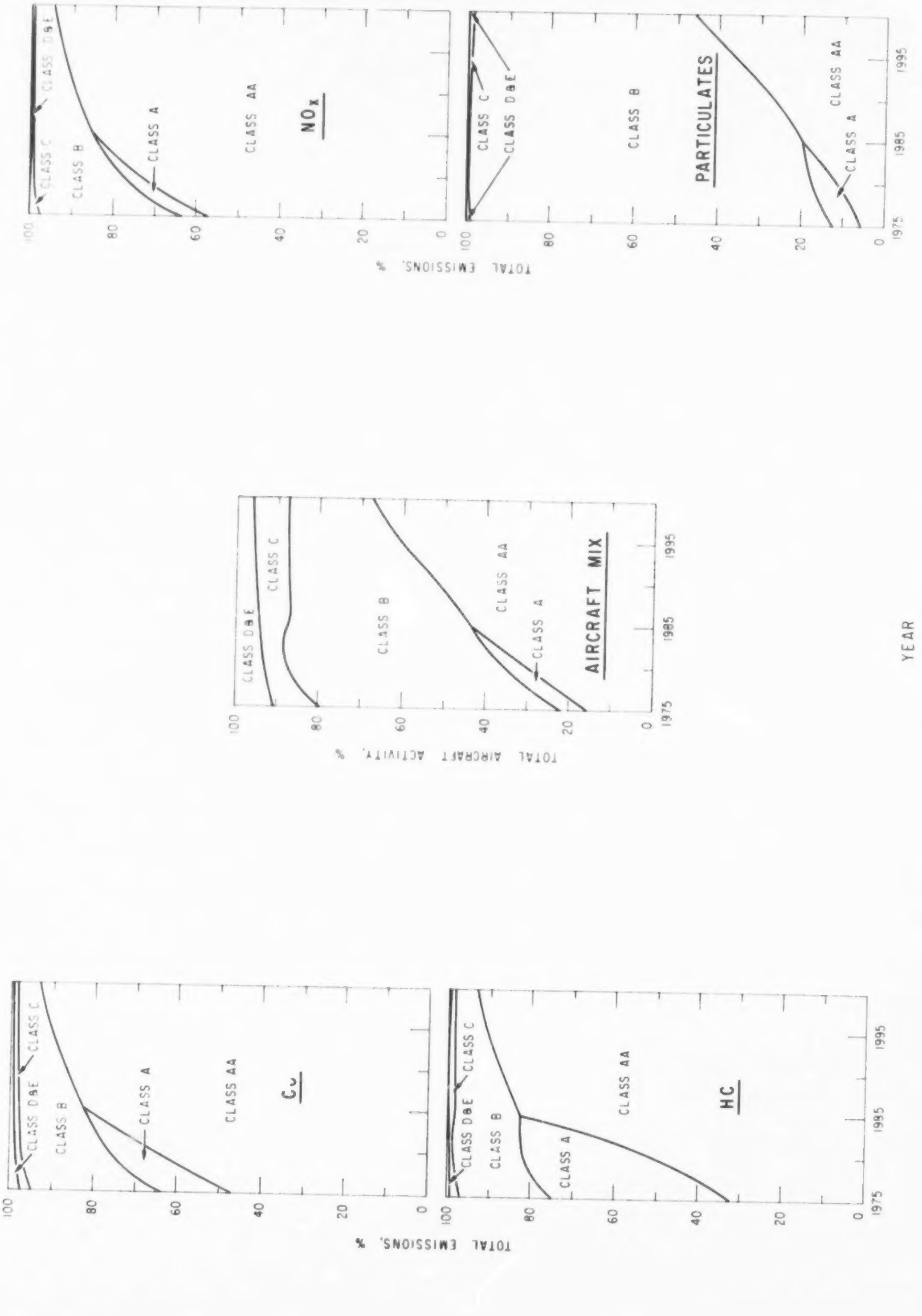


Fig. 5.2 Aircraft Emissions by Mix
St. Louis Airport, Speas Forecast

the phasing out of Class A aircraft will result in an improved HC emission rate, since these aircraft contribute more than their proportional activity would indicate.

For particulates, Fig. 5.2 shows that even over the length of the forecast period, Class B (727/DC9) aircraft will be contributing more than their proportional activity. Their gradual phasing out of service helps to keep the particulate emission rate constant. If it is deemed necessary, however, to reduce particulate emissions from aircraft it will be necessary to focus intial attention on this class of airplane.

In the forecast period, any attempt to impose emission controls on Class C, D, and E aircraft will probably have a negligible effect on emissions. This is true because their relative contribution to the emission load is extremely small. If, however, the emissions from other aircraft sources are controlled to bring them into line with their relative activity levels, then the Class C, D, and E aircraft could be considered for controls. In essence, they are a secondary emission source requiring control only after the other primary sources are controlled.

It should be noted that the above conclusions apply to the St. Louis airport aircraft mix. In referring to the application of controls to aircraft emissions, it is important to realize that other airports may require the primary controls be placed on different aircraft. Thus, when reference is made to emission control by aircraft type, it is intended to imply the type of control that could be applied locally, such as limitations on engine idle time. Emission controls on aircraft engines must be considered from the national perspective. To illustrate the differences, Table 5.1 shows the relative activity level and relative contribution to emission rates from

Table 5.1

Aircraft Emissions by Mix

Chicago O'Hare International Airport

1972

Aircraft Class	Activity Level%	Relative Emission Contribution (%)			
		CO	HC	NO_x	Particulates
AA	3.5	4.9	1.7	16.5	0.8
A	27.5	67.6	87.8	32.7	29.9
B	51.2	24.8	8.9	45.7	68.3
C	6.1	1.2	0.7	2.1	0.3
D & E	11.7	1.5	0.9	3.0	0.7

the aircraft mix at Chicago's O'Hare airport. Here,the Class AA aircraft contribute only slightly more than their relative activity to the CO emissions and less to the HC emissions. The NO_x and particulate rates are similar to that for St. Louis. This information is, of course, valid for the one year only.

Emissions by Mode

Another piece of data which adds to the utility of the overall analysis is the distribution of air pollutant emissions among the various modes of aircraft operations. It is known that in general the CO and HC emissions are greatest during the taxi and idle portions of the LTO cycle and the NO_x emissions are greatest during the high-thrust takeoff and climbout portions. A quantitative presentation of this information is necessary to make any decisions on the expected effectiveness of emission controls which call for alterations in the operational cycle.

Table 5.2 gives the fraction of the total emission that is released from each portion of the LTO cycle as calculated for 1990 using the Speas forecast. For CO, HC, and NO_x, the other years of the forecast show only slight changes from the fractions given on Table 5.2. A significant change is observed in the distribution for the particulate emissions. This can be explained by looking at the emission factors of Table 3.33 and the relative particulate emission contribution of each aircraft class. The JT3D and JT8D engines in use on Class A and Class B aircraft have very low particulate emissions during the taxi and idle modes as compared to the other modes. The JT9D shows a more even distribution among all modes. Hence, as the activity levels of the Class A and B aircraft are reduced, the modal distribution of particulate emissions approaches that of the Class AA aircraft.

Table 5.2

Aircraft Emissions by Mode of LTO Cycle

St. Louis Airport

1990 - Speas Study

Mode	Percent of Emissions Coming from Mode					
Pollutant	Taxi	Idle	Approach	Landing	Takeoff	Climbout
CO	66.1	23.5	6.4	2.1	0.3	1.6
HC	70.1	24.1	2.4	2.1	0.3	1.0
NO_x	5.6	2.4	11.3	6.7	21.4	52.6
Particulates	17.9	6.1	26.0	4.1	9.4	36.5
(Range)*	7.8-26.8	2.1-10.3	31.2-22.0	4.5-3.7	11.1-7.6	43.3-29.6

*The contribution to particulate emissions by each mode varies over the forecast period 1975-2000. The 1990 value and the range of variation are given.

Table 5.2 illustrates that for the St. Louis airport, substantial reductions in CO and HC emissions can be effected by the modification of ground operations. The taxi and idle modes account for 89.6 and 94.1% of the CO and HC emissions, respectively. A reduction of 50% in taxi-idle time could, therefore, decrease the total aircraft CO and HC emissions by about 45% and 47%, respectively. Techniques for reducing this taxi-idle time, such as towing aircraft into position rather than having them move under their own power, must, therefore, be given major consideration in the control of emissions. (There are, unfortunately, other considerations which can greatly change the viability of this technique. The safety aspects of such a modification have not yet been fully evaluated. As with almost all engineering systems, benefit is not gained without paying a price for it).

Table 5.2 also shows that modification of ground operations will do little to improve the NO_x emission picture. Only 8% of the total NO_x emitted comes from ground operations. It is highly unlikely that substantial modifications for the sake of reducing NO_x emissions can be made in the flight modes without adversely affecting the safety of the aircraft. Hence, it appears that any required NO_x emission reduction will have to come from controls placed on the aircraft engines themselves. NO_x control, therefore, is out of the reduction ability of the local airport operator.

Particulate emissions can be partially controlled by the changes in ground operation but not nearly as dramatically as CO and HC. In 1990, a 50% reduction in taxi-idle time would result in about a 13% reduction in particulate emissions. By 2000, this could be as much as 20%.

Thus, the simple task of displaying the emissions by mode of aircraft operation has provided several starting points from which to approach the evaluation of alternative aircraft emission controls.

Emission Trends

From the standpoint of regional air pollutant emission management, an item of concern would be the projected trend in aircraft emissions. One index of this trend is the average pollutant emission rate per aircraft LTO at the study airport. This is obtained by dividing the annual amount of pollutants emitted from all aircraft by the annual number of aircraft LTOs. Figure 5.3 depicts this computation for the Speas forecast for the St. Louis airport. It can be seen that the trend is toward higher aircraft emission rates in CO and NO_x, somewhat higher rates for HC and lower rates for particulates. The implication is that on a per airplane basis, the emission situation is worsening for CO, HC, and NO_x and improving for particulates.

This does not, however, complete the picture. Consideration of only the above information might indicate that from an emission standpoint, it would be more profitable to have passengers travel in many smaller, lower-emitting aircraft rather than a few larger, higher-emitting ones. This preliminary conclusion could have important implications if it were decided to control airport air pollution by regulating the aircraft mix. The conclusion does not stand up under further investigation. A more revealing index of emission trend is the average pollutant emission rate per enplaned passenger. Figure 5.4 is a plot of this rate for the Speas forecast. The curves show a decrease in emissions per passenger for all pollutant species with the exception of a slight increase in NO_x for the 1975-1985 period. The salient feature of this display is that the trend toward the wide body jets is resulting in the movement of passengers at an improved air pollutant emission level. The air transportation system is improving its position in the transportation/air pollution picture by moving people in and out of airports with less emissions per person.

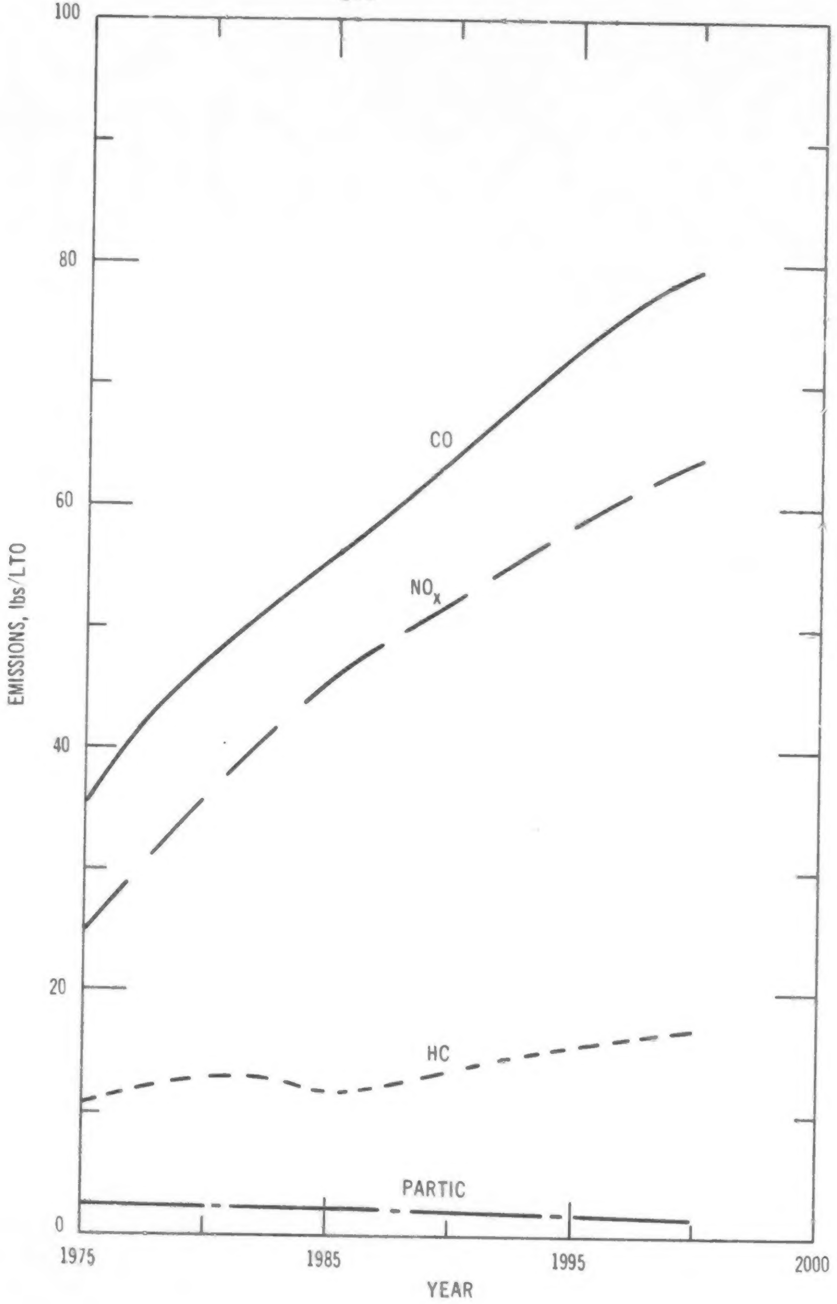


Fig. 5.3 Aircraft Emissions per LTO Cycle
St. Louis Airport, Speas Forecast

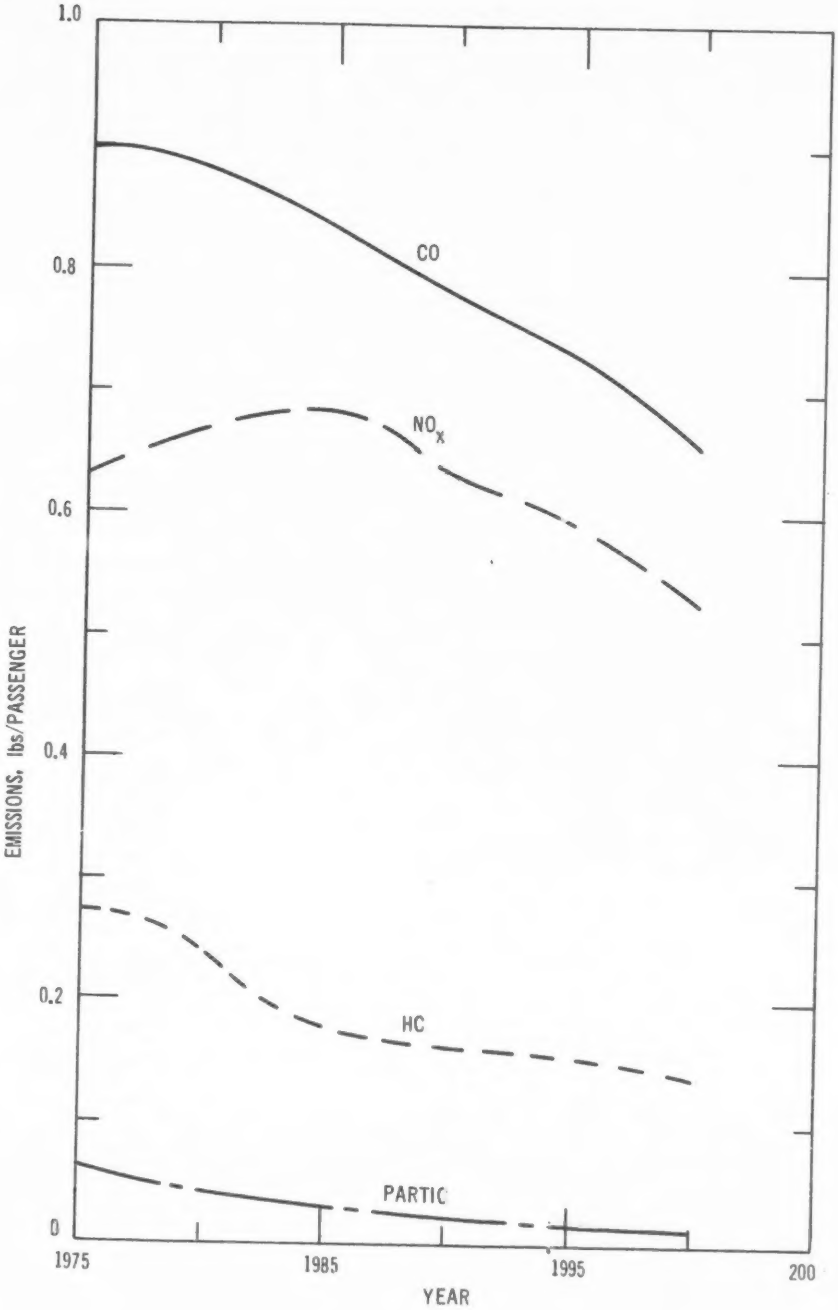


Fig. 5.4 Aircraft Emissions per Enplaned Passenger
St. Louis Airport, Speas Forecast

Table 5.3

Average Aircraft Emissions

O'Hare International Airport

1972

Pollutant	Average Emission Per Aircraft LTO (lbs)	Average Emission Per Enplaned Passenger (lbs)
CO	55.45	1.05
HC	32.71	0.62
NO_x	19.51	0.37
Particulates	3.30	0.06

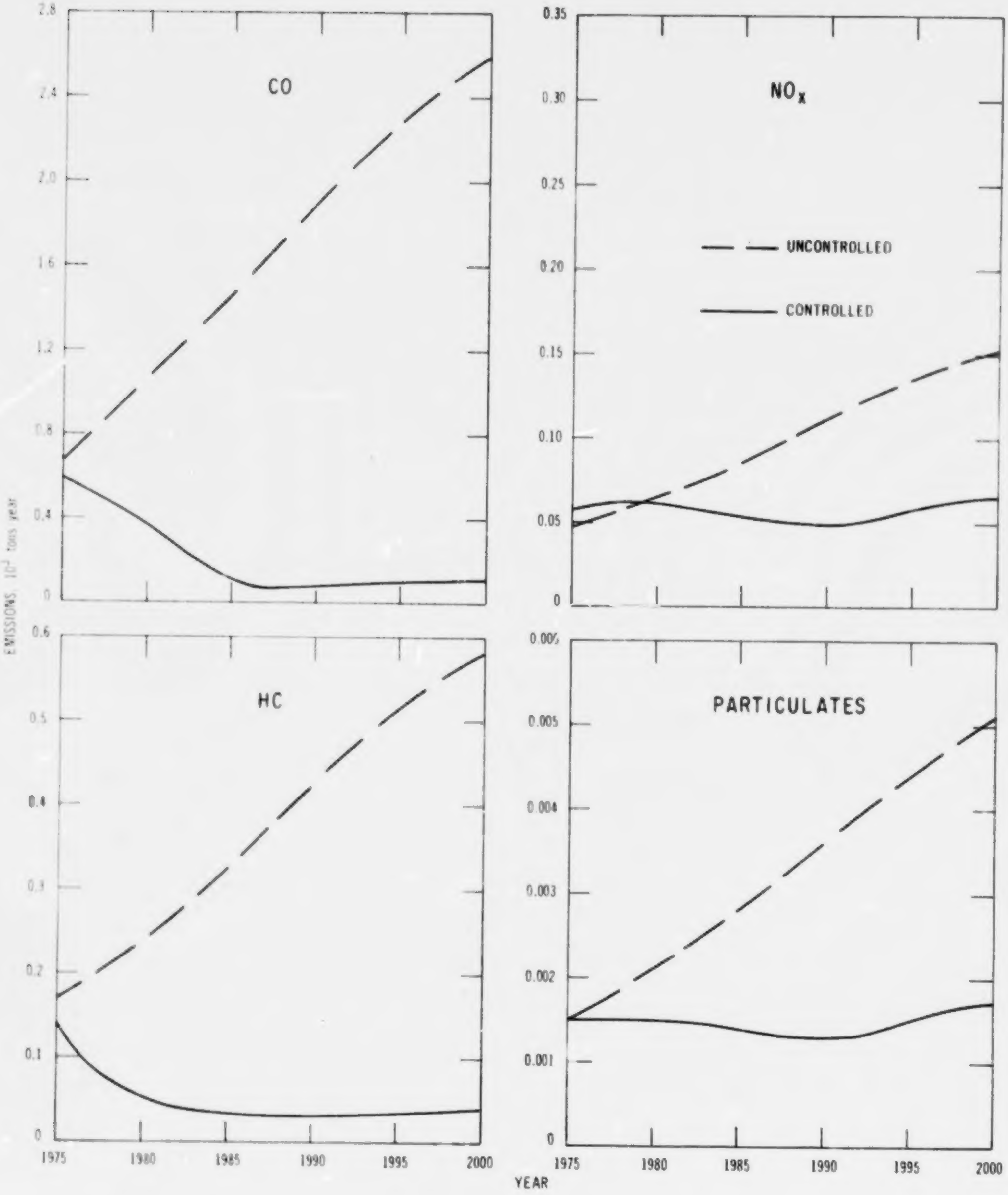


Fig. 5.5 Annual Ground Service Vehicle Emissions
St. Louis Airport, Speas Forecast

vehicles represent a significant source of air pollutant emissions and are likely candidates for some form of emission control. Such controls could reduce overall airport emissions with little or no impact on safety.

It is reported[36] that at the new Dallas-Ft. Worth airport, consideration is being given to the adaptation of ground service vehicles to burn propane gas in order to meet the 1975-76 federal automotive emission standards. Figure 5.5 shows the effect these standards would have on reducing ground service vehicle emissions at the St. Louis airport. In 1990, the CO emissions could be cut by about 96%, the HC by 93%, the NO_x by 67%, and the particulates by 64%. This, then, offers airport planners one safe method of exercising local control over airport emissions.

5.1.3 Fuel Storage and Handling System

Since the emissions from fuel storage and handling are based on the total airport fuel requirements which, in turn, are based on aircraft activity, the emission growth pattern is the same as that for aircraft. Table 5.4 gives the total hydrocarbon emissions from fuel storage and handling, as calculated for each of the three forecasts for the St. Louis airport.

The imposition of controls to eliminate this emission source would require some sort of vapor recovery system to be installed on the fuel tanks of all aircraft and ground service vehicles. If such a system could be designed to be compatible with the requirements of weight, size, and safety, the emissions could be effectively reduced to zero.

5.1.4 Engine Test and Maintenance Facility

The emissions from engine testing is also dependent on the aircraft activity and therefore follows the same growth trend. Table 5.5 gives these calculations for the St. Louis airport. The discussion on aircraft emission rates (Section 5.1.1) explains the behaviour of these emission patterns.

Table 5.4

Annual Fuel Storage and Handling Emissions

St. Louis Airport

Year	Hydrocarbon Emissions (tons/year) NADC	McDonnell	Speas
1975	-	79	101
1980	92	100	114
1985	114	124	135
1990	134	155	161
1995	162	-	179
2000	185	-	191

Table 5.5

Annual Engine Testing and Maintenance Emissions

St. Louis Airport

	Emissions (tons/year)											
	NADC				McDonnell				Speas			
Year	CO	HC	NO_x	Particulates	CO	HC	NO_x	Particulates	CO	HC	NO_x	Particulates
1975	-	-	-	-	66	39	8	1	50	15	10	3
1980	56	17	11	2	85	44	13	1	63	17	13	3
1985	73	20	16	2	103	45	18	2	80	17	19	3
1990	93	23	21	2	126	48	24	2	99	20	23	3
1995	116	26	27	2	-	-	-	-	120	25	29	3
2000	135	27	32	2	-	-	-	-	137	28	33	3

Apart from controls placed on the aircraft engines themselves, it is not clear that these emissions can be controlled by the airport operator. Conceivably, the test cell could be designed to control emissions with afterburners, catalytic converters and the like. The costs and resulting benefits of such an elaborate installation are probably not warranted, however.

Alternatively, some modification of the test cycle could be made. A higher power setting could be used to minimize CO and HC emissions, while sacrificing a little on the NO_x emissions. This would probably result in other tradeoffs, however, such as increased noise and inability to perform necessary tests on engine performance.

In unusual circumstances which require reduction of emissions from every possible source, the number of tests could be curtailed. In summary, it can be said that the reduction of air pollutant emissions from engine testing is not within the feasible and practical control of the local airport operator and must rely on engine emission regulations.

5.1.5 Heating and Air Conditioning Plant

The emissions from the airport heating and air conditioning plant are a function of a number of variables which fall within the realm of control of airport designers. Items such as choice of fuel, building size, building thermal insulation, and others are decided upon by airport master-planners prior to any construction. The actual decision, however, is usually made upon considerations other than air pollution emission control. These considerations, chiefly economic, are not easy to override in order to achieve emission reductions. One variable, however, has been investigated for its impact on St. Louis airport emissions and that is the choice of fuel. Table 5.6

Table 5.6

Annual Airport Heating Plant Emissions

St. Louis Airport

Pollutant	Emissions (tons/year)	
	Coal-Fired Plant	Oil-Fired Plant
CO	22.3	0.4
HC	11.2	5.3
NO_x	167.3	70.0
Particulates	24.5	24.5

gives the emissions resulting from a coal-fired and an oil-fired heating plant. Both are subject to Illinois state regulations, as discussed in Section 3.2.5.

It is clear that an oil-fired plant will result in smaller emission rates. The equivalence of the particulate emission rate is a result of the application of the state regulations. To meet this standard, the coal plant would require about 98% reduction of uncontrolled emissions, while the oil plant would require only 26% reduction. The final decision on fuel choice will require an analysis of the overall fuel costs, as compared to the cost of equipment needed to meet state requirements.

Another alternative method of reducing emissions would be to decrease the energy requirements of the buildings by use of new thermal insulation materials. Some of these materials, such as highly reflective glass, have already been installed on some of the newer office buildings. The resulting decrease in energy requirements would proportionately reduce heating plant emissions. Again, economic considerations would tend to dominate the final decision.

5.1.6 Access Traffic

Access traffic is the second largest source of airport emissions and is exceeded only by the aircraft. Although automotive emissions do not fall under the direct control of the airport planner, there are indirect measures, such as reduction of traffic congestion, which can indirectly reduce the emission load.

Figure 5.6 is a display of the access traffic emissions as calculated for the St. Luois airport, Speas forecast. The substantial dip in the curves is a result of the imposition of the 1975-76 federal automotive emission

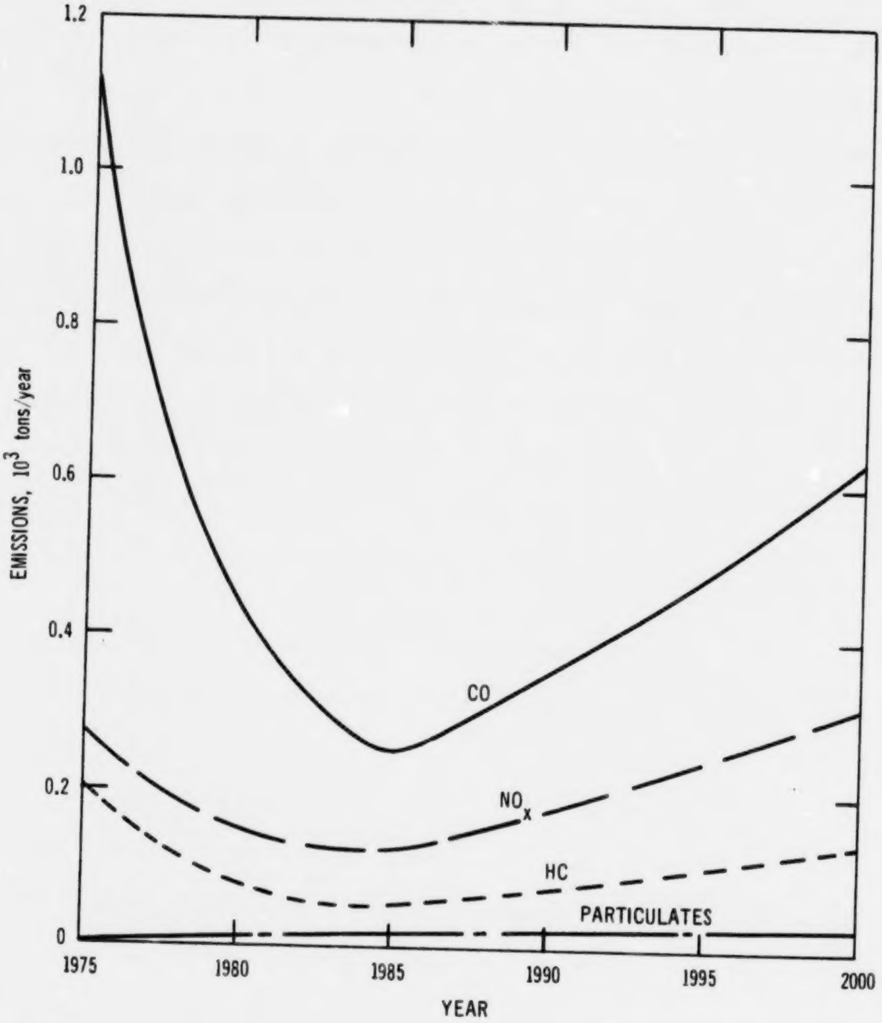


Fig. 5.6 Annual Access Traffic Emissions
St. Louis Airport, Speas Forecast

standards. As more controlled vehicles are phased into the population, the total emission load decreases even though the actual vehicle traffic is increasing. By 1985, however, essentially all of the vehicles are controlled and the increase in traffic volume begins to outweigh the advantages of the emission controls.

It should be noted that these calculations are based on the assumption that no additional automotive controls will be imposed beyond the 1975-76 standards and that the airport design will minimize traffic congestion. Should congestion become a major problem, the emission rates could conceivably double. (The correction factors for CO and HC are about 2.1 and 1.7, respectively,[28] when average vehicle speed is reduced from 25 mph to 10 mph.) Minimization of this problem in the airport design will enable a significant emission source to be held in check.

Alternate Access Modes

One of the airport design considerations now being emphasized is the diversion of people who now access the airport by private automobile to some other form of transportation. Because of the general nature of the airport access model described in Section 3.1.8, it was possible to evaluate the impact on air pollutant emissions of alternate access modes. A "numerical experiment" was carried out by changing the access mode choice of the different groups of people over the range of 100% private auto to 100% mass transit.

Figures 5.7a, b, c, d, show the results of diverting people from autos to buses, diesel commuter trains, and electric rail rapid transit.

CO

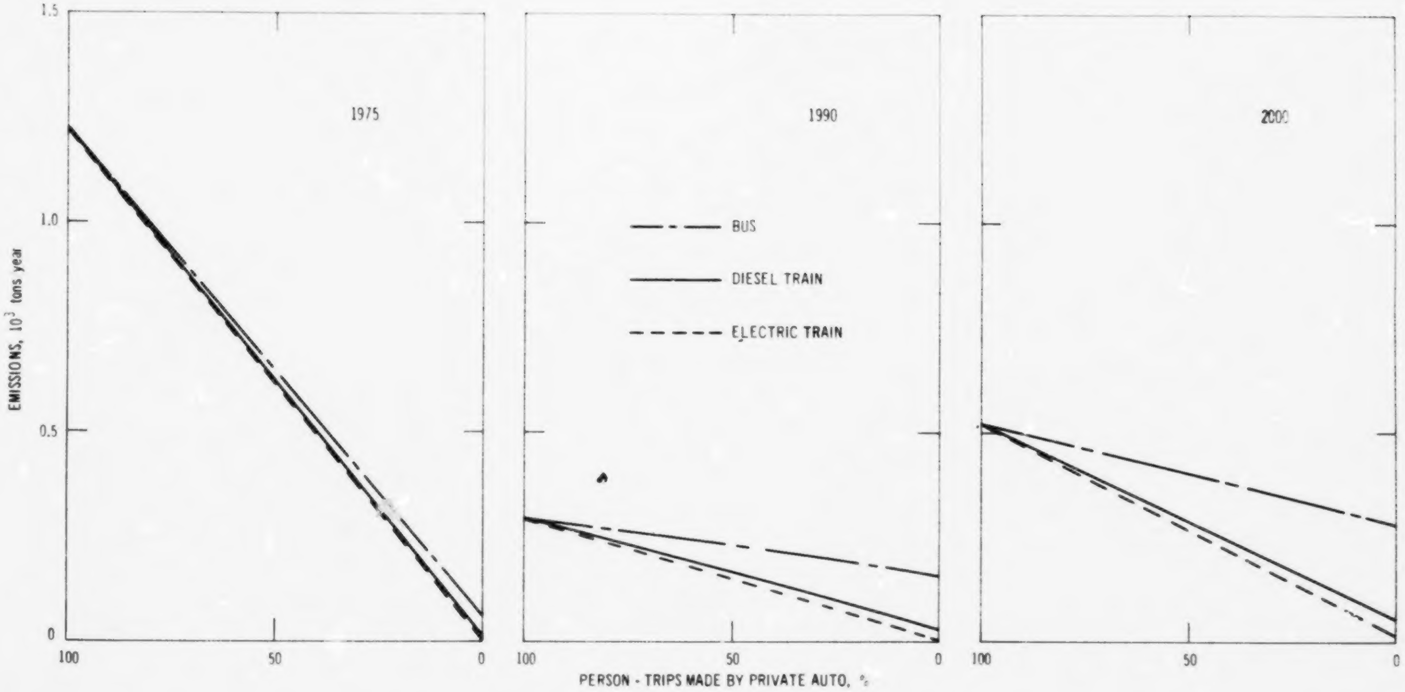


Fig. 5.7a Emission Impact of Alternate Access Modes
St. Louis Airport, Speas Forecast

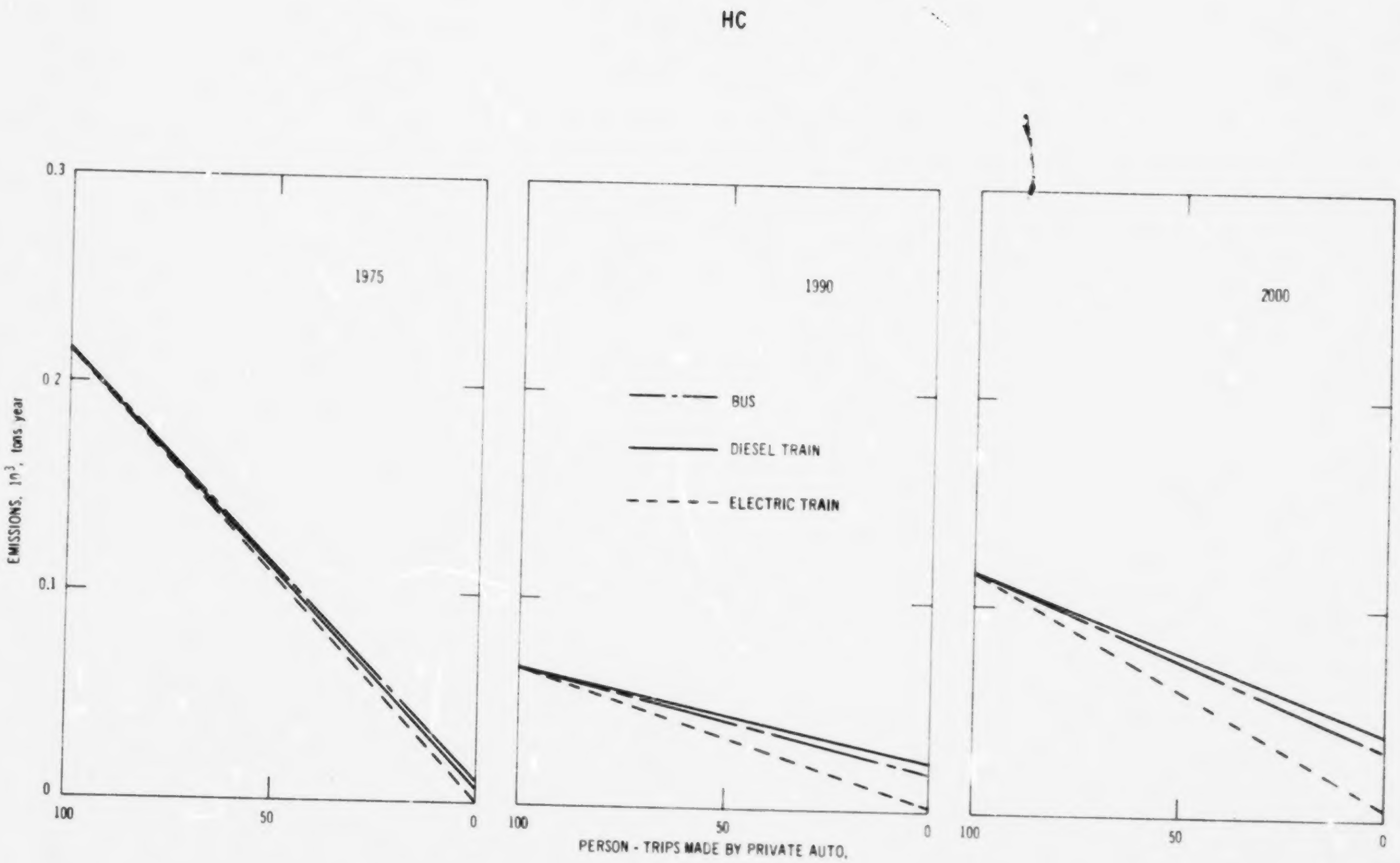


Fig. 5.7b Emission Impact of Alternate Access Modes
St. Louis Airport, Speas Forecast

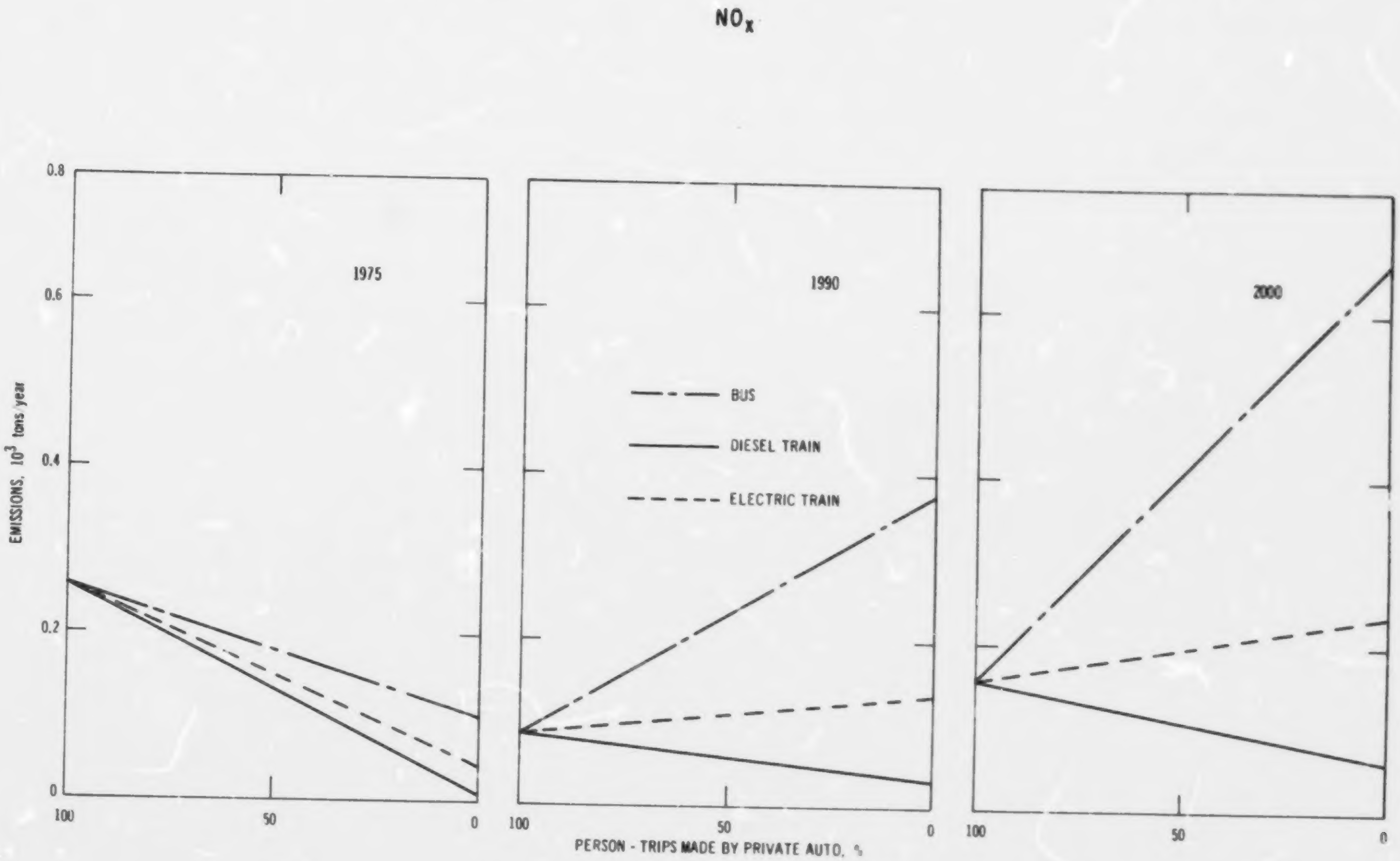


Fig. 5.7c Emission Impact of Alternate Access Modes
St. Louis Airport, Speas Forecast

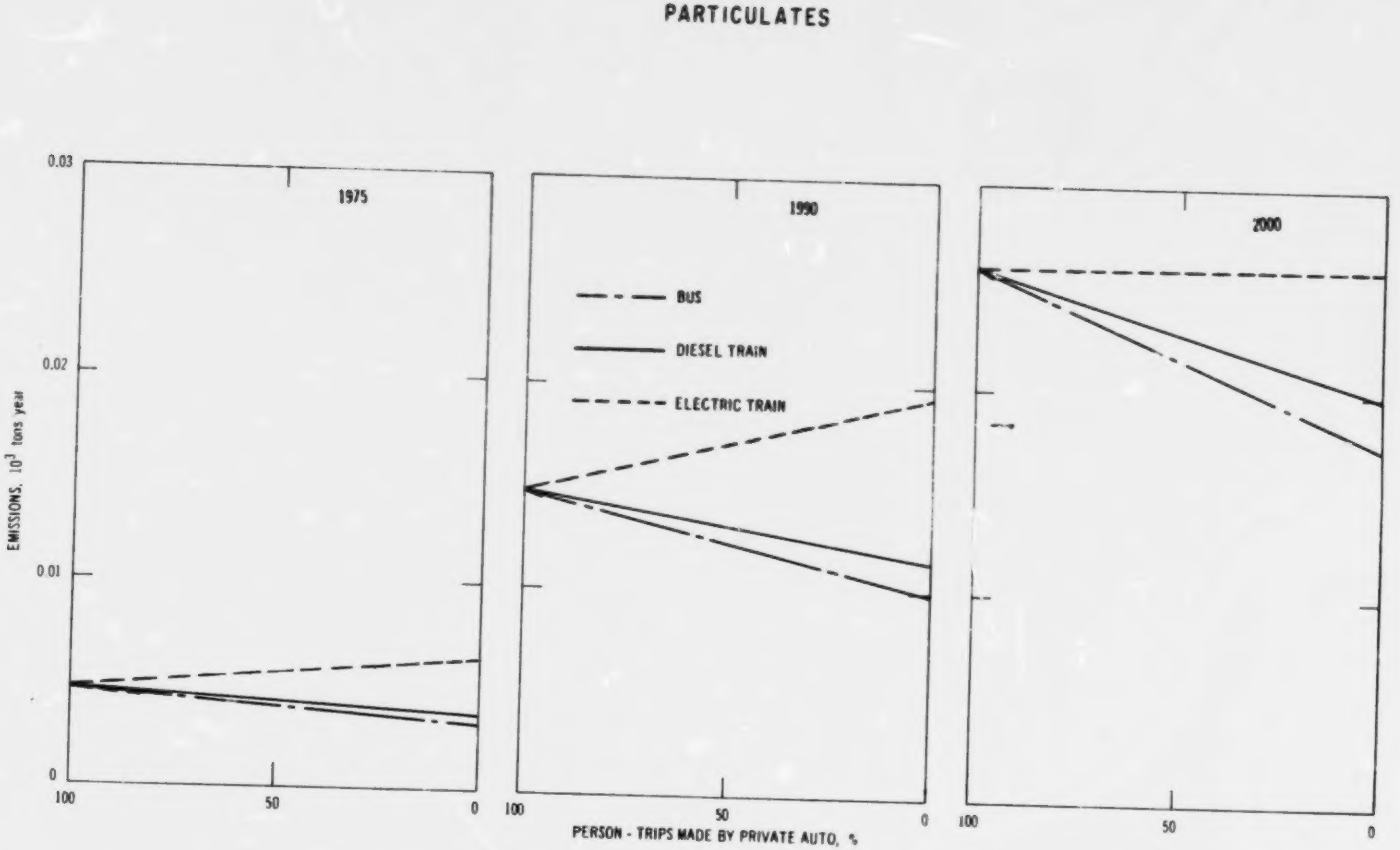


Fig. 5.7d Emission Impact of Alternate Access Modes
St. Louis Airport, Speas Forecast

The results indicate that in 1975, a significant reduction in CO, HC, and NO_x emissions can be had by diverting people from autos to mass transit. A slight increase is observed in particulate emissions resulting from the electric rail rapid transit power plant. It can also be seen that, with the exception of particulates, there is not much difference among the three mass transit modes in emission improvement.

By 1990, the improvement in CO and HC emissions is not nearly as dramatic as a result of the imposition of emission controls on autos. In fact, the NO_x emissions increase markedly if diversion is made to buses, and increase, somewhat, if diversion is made to electric rail transit. The diesel train, because of its higher passenger capacity, is the only mode which shows an NO_x emission improvement in a 1990 tradeoff.

By 2000, the tradeoff in CO and HC emissions has improved, although not reaching the 1975 level. This is a result of the increase in auto volume required to handle the increase in person-trips to the airport, overtaking the improvements brought about by emission controls. The NO_x picture is worse than in 1990 for the bus and electric rail transit; it is improved for the diesel train. The particulate tradeoff has improved for all three modes.

Based upon the above calculations for the St. Louis airport over the period 1975-2000, it appears that the diesel commuter train, because of its higher passenger capacity, is the best alternative to the automobile from an emissions standpoint. The electric rail transit is next, with the bus last because of its high NO_x emissions. It should be noted that several conditions could conceivably come together to change this picture. First, the imposition of emission controls on diesel bus NO_x emissions could substantially improve its position in a tradeoff. Second, any significant traffic congestion could so deteriorate the CO and HC emissions as to make the tradeoff to mass transit attractive throughout the forecast period. Third, use of higher capacity electric trains and the imposition of stricter emission controls on power plants could put them in a better position with respect to the diesel trains.

This type of tradeoff study, although not comprehensive and certainly not completely conclusive, is the type of information that can and should be generated by airport planners in evaluating alternative emission control strategies.

5.1.7 Total Airport Emissions

The final segment of the airport emission display is the summation of the individual contributions into the total emission rate. It is this rate that will result in impacts on the regional air quality. The diurnal patterns of this emission load are important in determining compliance with federal ambient air quality standards. The relative magnitude of the various emission sources needs to be displayed also to determine those sources which should be subject to immediate controls and those which can be treated as secondary contributors.

Annual Airport Emissions

Figure 5.8 gives the annual total airport emissions as calculated for the St. Louis airport. In this display, the controlled ground service vehicle and the oil-fired heating plant emissions are used. The presentation of the computations for the three air traffic forecasts illustrates the range of emissions that results from the range of forecasted activity. Emission

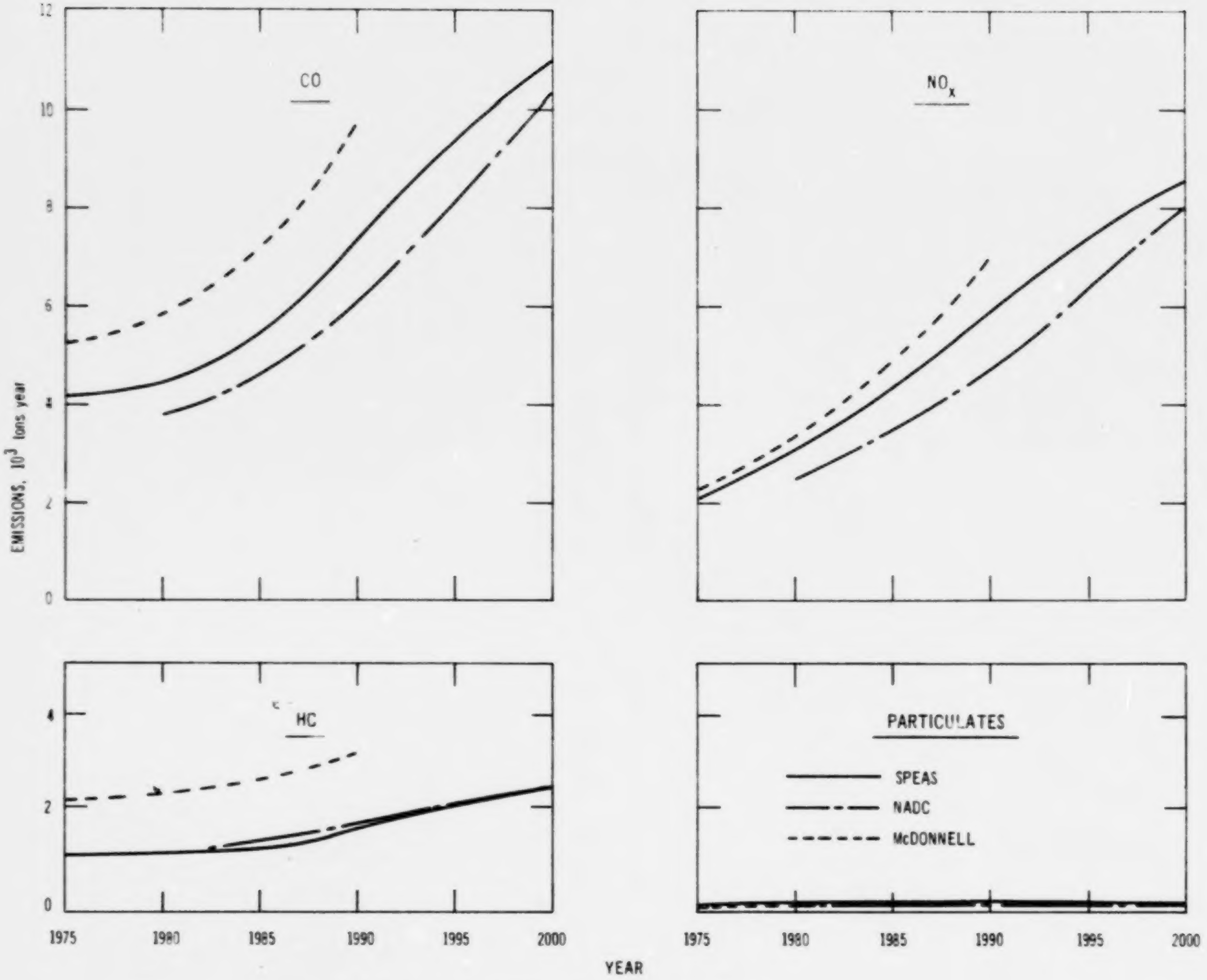


Fig. 5.8 Annual Total Emissions
St. Louis Airport

ranges can be presented as a function of other parameters but the important ones have already been discussed in the sections on individual emission sources.

The figure shows that the NADC and the McDonnell forecasts act essentially as upper and lower bounds on CO and NO_x emissions. The widest variation is in 1990, where the CO emissions are between 6041 and 9734 tons/year and the NO_x emissions are between 4699 and 6950 tons/year. The Speas forecast seems to naturally fall as a mean; it is, therefore, suggested that the Speas calculations be used as the emission estimate with the possible range of emissions noted. For hydrocarbons, the Speas and NADC calculations almost coincide with the McDonnell values as an upper bound. For particulates, all three forecasts are close together.

The Environmental Impact Statement[1] suggests that the total airport emissions based on the 1990 Speas forecast would be on the order of 10,400 tons CO, 4100 tons organics, 5000 tons NO_2, 3000 tons particulates per year. The CO, HC and NO_x estimates are comparable to the higher McDonnell projection, but the particulate estimate is an order of magnitude higher than all three projections. It is not possible to do a detailed evaluation of the differences because insufficient information on the calculation assumptions used in the Impact Statement is available.

Another method of presenting this data is in the form of emission density. This would mean dividing the total emission rate by the area of the airport to get an emission density in units of tons/mile^2/day. A graphical display of this data would require only a scale change on Fig. 5.8 . In computing the emission density for the Columbia-Waterloo site, the land area used must be carefully considered. The Impact Statement states that the total airport boundary is expected to cover approximately 29.1 sq.mi. Of that area, only 7.4 sq mi is expected to be utilized for actual airport activity (runways and taxiways, terminal buildings, airport facilities), with an additional 7.0 sq mi used for environmental buffer zones in the pre-2000 period. An additional 10.4 sq mi is expected to be added for airport activity, and 4.3 sq mi for buffer in the post-2000 period. If the total 29.1 sq mi airport area were to be used for emission density calculations, the Columbia-Waterloo site would show a remarkable improvement over existing airports. O'Hare Airport in Chicago has only about 10 sq mi. Table 5.7 shows the emission densities for O'Hare, as compared to the Columbia-Waterloo site in 1990 when the passenger activity will approximately equal O'Hare's. Both the 29.1 sq mi total area and the 7.4 sq mi pre-2000 airport activity area are used for the St. Louis airport.

It can be seen that on the basis of the total airport area, the Columbia-Waterloo site will be well below current emission densities, but on the basis of the active area, the NO_x emission density is actually higher than current values. This indicates that airports may be as significant an air quality problem to themselves as they are to the surrounding region. The air in the active area is subject to a much higher emission density loading than the whole airport imposes on the region. This indicates the need to consider local air quality impacts, as well as regional impacts when planning for airport emission controls.

Diurnal Emission Patterns

Figure 5.9 gives the daily pattern of emissions as calculated for the St. Louis airport using the 1990 Speas activity level. It can be seen that the emission rate begins to climb at about 6:00 AM and continues until a daytime average level is reached at about 11:00 AM. This level is maintained until about 7:00 PM, whereupon it begins to decline to a nighttime

Table 5.7

Airport Emission Densities

Airport	Area	Emission Density (Tons/sq mi/yr)			
		CO	HC	NO_x	Particulates
O'Hare	9.9	1828	783	456	112
Columbia-Waterloo (1990)	29.1	253	59	201	8
	7.4	993	234	791	32

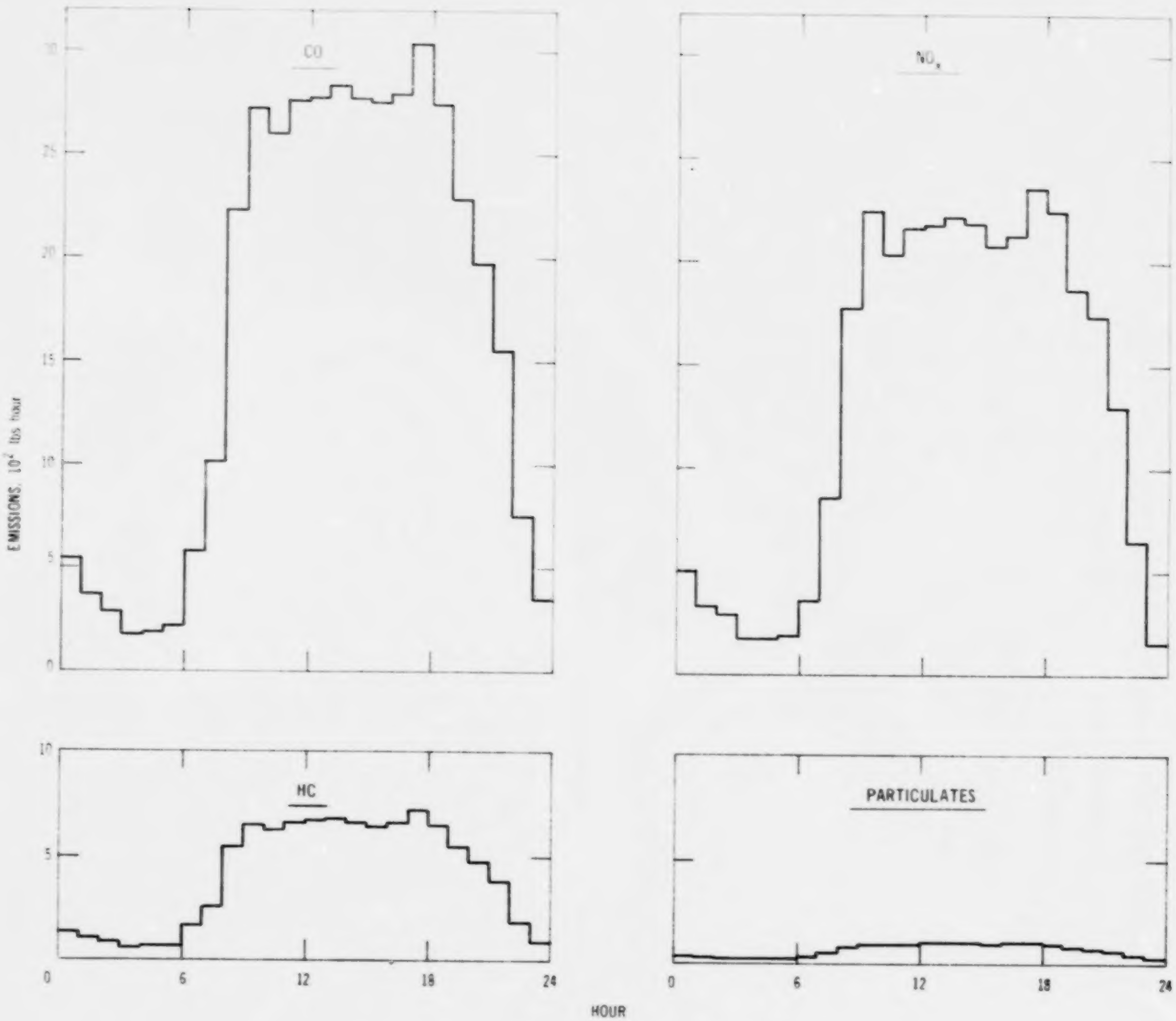


Fig. 5.9 Diurnal Emission Pattern
St. Louis Airport

level which reaches its low point at about 3:00 AM. Distinct peaks in the emission rates can be seen in the 8:00-9:00 AM and 5:00-6:00 PM time periods corresponding to peaks in automobile and aircraft activity.

This display can be used to make some statements about the expected air quality, as compared to the national ambient air quality standards. The CO standards are based on both 1-hour and 8-hour average concentrations. Figure 5.9 shows that the high average daytime CO emission rate is sustained for at least ten hours and that 1-hour peaks are observed above that level. It is conceivable, therefore, that if the average emission rate is high enough both the 1- and 8-hour standards could be violated on the airport grounds.

The hydrocarbon standard is based on a 3-hour average during the period of 6:00-9:00 AM (morning rush period). It is designed to limit the midday oxidant formation. The figure shows that the emission rate is beginning to increase during these hours and could, therefore, result in excessive oxidant air quality levels if the daytime average emission rate is high. On the other hand, if the daytime average rate is not too high, the 1-hour photochemical oxidant standard could conceivably be met since the hydrocarbon emission rate does not exhibit strong peaks.

The NO_x standard is based on an annual average and no specific information can be gleaned from Fig. 5.9.

The particulate standard uses an annual and a 24-hour averaging time. Thus, it is only the total daily emissions that would be used for comparison to air quality standards.

One additional point needs to be made about the diurnal emission pattern and that is the emission rate during the design peak hour. As

Table 5.8

Peak Hour Emission Rate

St. Louis Airport
1990 Speas Forecast

	Emission Rate (lb/hr)			
	CO	HC	NO_x	Particulates
Average peak hour (from Fig. 5.9)	3026	712	2354	91
Design peak hour % increase	3552 17	825 16	2695 14	104 14

Table 5.9

St. Louis Airport Emissions
Speas Forecast
(Ton/Year)

Pollutant	Source	Year					
		1975	1980	1985	1990	1995	2000
CO	Aircraft	2377	3576	4990	6805	8613	10040
	GSV*	594	367	106	83	101	114
	Engine Test	50	63	80	99	120	137
	Heating Plant†	0.4	0.4	0.4	0.4	0.4	0.4
	Access Traffic	1140	440	249	361	486	632
	Total	4162	4447	5425	7348	9320	10924
HC	Aircraft	721	974	1050	1437	1822	2125
	GSV*	142	53	35	30	36	40
	Fuel Handling	101	114	135	161	179	191
	Engine Test	15	17	17	20	25	28
	Heating Plant†	5	5	5	5	5	5
	Access Traffic	205	80	53	78	105	136
	Total	1190	1243	1296	1731	2171	2525
NO_x	Aircraft	1672	2718	4111	5531	6946	8054
	GSV*	57	61	54	48	58	66
	Engine Test	10	13	19	23	29	33
	Heating Plant†	70	70	70	70	70	70
	Access Traffic	273	149	124	180	242	315
	Total	2082	3011	4377	5852	7344	8537
Part.	Aircraft	165	177	180	192	187	177
	GSV*	2	2	1	1	2	2
	Engine Test	3	3	3	3	3	3
	Heating Plant†	25	25	25	25	25	25
	Access Traffic	6	8	12	17	23	30
	Total	199	213	221	238	238	235

*Ground Service Vehicles (Controlled)
†Oil-Fired

Note: Numbers independently rounded may not add exactly.

discussed in Section 3.1.3, one of the forecast parameters for the St. Louis airport is the peak hour aircraft activity. This is somewhat higher than the peak hour activity generated by applying the diurnal pattern of Table 3.11 to the annual activity estimates of Table 3.10. This additional peak hour load is a result of seasonal variations and represents the maximum activity that the airport is designed to handle. For the purposes of an air quality analysis, the resulting increase in air pollutant emissions during the design peak hour is of importance only for those pollutants with short averaging time standards, namely, CO, hydrocarbons, and photochemical oxidants. Table 5.8 shows the computed peak hour emission rate for the 1990 Speas forecast and compares the rate from Fig. 5.9 to the rate at the design peak hour activity level. An increase of from 14-17% in emissions is observed. If the CO and oxidant air quality is marginal to begin with, this increased emission rate could result in a serious degradation of the air quality.

Relative Emission Strengths

In attempting to evaluate the possibilities of emission restrictions placed on airport activities, it is necessary to know the relative strengths of each of the emission sources. The final airport emission display is a summary tabulation of all sources so that the primary contributors can be isolated from the minor sources. Table 5.9 presents this tabulation for the St. Louis airport. A similar compilation for O'Hare is presented later on Table 5.10.

The tabulation shows that early in the forecast. Aircraft and ground vehicles (service and access) contribute equally to the CO emission load. Later, however, the imposition of emission controls on motor vehicles essentially reduces their contribution to an order of magnitude less than the aircraft. Essentially the same can be said for the HC emission rates. For NO_x and particulates, the aircraft start out as overwhelming contributors and remain that way throughout the forecast period.

The indication is that some form of control is required on aircraft emissions. It was hoped that the recent federal EPA aircraft standards[45] could have been included in this study, but their late issuance precluded this possibility.

For hydrocarbon emissions in the post-1975 period, the fuel handling system would appear to be the prime target for control, other than aircraft. The implications of controlling this source have already been discussed.

The airport heating plant is not significant in the CO and HC picture but contributes substantially to the NO_x and particulate emissions. Additional stationary source regulations would have to be issued to control this.

Engine testing is most significant in the CO and HC emission rate. This is primarily because the idle power setting is used for most of the test and this is the highest CO- and HC-emitting mode.

It should be pointed out that the above conclusions are based on looking at the emission rates only. In order to determine if, in fact, any emission controls are required, it is necessary to do an air quality calculation using these emission rates as input. This is planned for Phase II of this program.

5.2 Airport Vicinity Land Use Emissions

This section presents some of the results of the land use based emission estimating methodology for the O'Hare airport study area. The procedures described in Section 4 were applied to each of the air pollutant producing land use classifications (residential, commercial, institutional, manufacturing, warehousing and motor vehicle emissions). Annualized emission rates for each of the five primary pollutants were computed for each individual section and then summed to provide a total emission rate per section for each pollutant. For purposes of comparing emissions on a density basis, the emission density of each section was also computed as well as the emission density of the O'Hare airport facility. The density for the airport was based on the total emissions for each pollutant divided by the airport property (approximately 10 square miles). Total airport emissions were developed using the procedures outlined in Section 3. The calculations were based on annual average emissions for 1970. However, for the airport emissions the levels are essentially equivalent to 1972 since the aircraft activity was nearly the same for both years. It is important to note here that the emissions calculated through this procedure are basically uncontrolled, that is, neither stationary source emission controls required by implementation plans nor Federal automotive emission limitations were effecting significant reductions at the time of this calculation.

Figures 5.10 through 5.14 present the display of emission densities for the individual sections of the study area in comparison with O'Hare airport emission densities. Table 5.10 indicates the airport and surrounding land use emissions broken down into the various activity components. While airport emission densities of CO, HC and NO_x are considerable, it can be shown that comparable densities are prevalent in the surrounding developed areas, where ground transportation emissions are an extremely large contributor.

It is fairly easy to relate the emission density figures to the major arteries and expressways in the airport vicinity. It should be noted that if the airport CO and HC emission density were computed based on the terminal areas of the airport (90% of total emissions), then the densities would increase by a factor of 5 to 10. Sulfur dioxide emission densities in the airport vicinity are considerable due to the build-up of the manufacturing activities. SO_2 emissions from the airport are composed largely of stationary heating plants with a small contribution from aircraft.

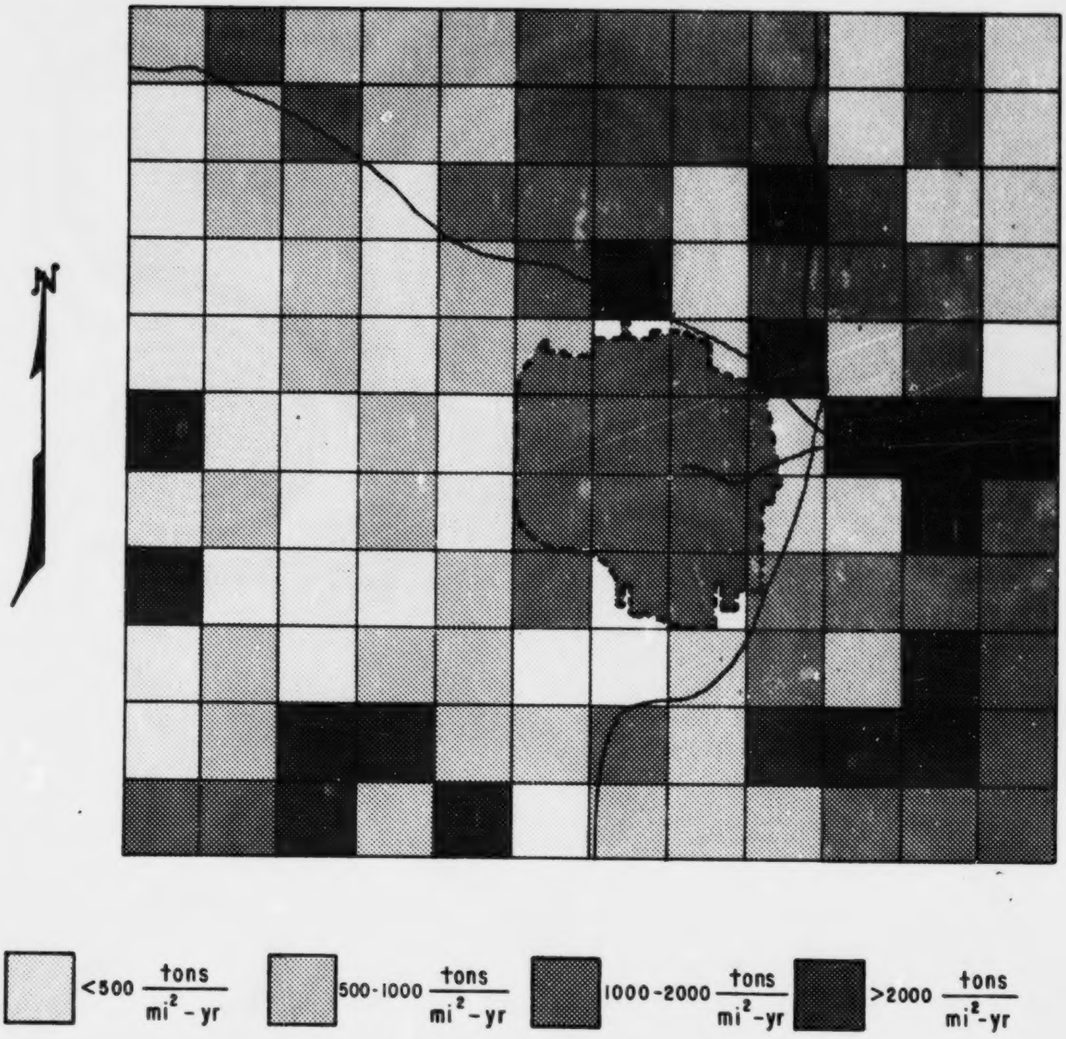

N
<500 tons / mi² - yr
500-1000 tons / mi² - yr
1000-2000 tons / mi²-yr
>2000 tons / mi²-yr

Fig. 5.10. Carbon Monoxide Emission Densities from O"Hare Airport and the Surrounding Area

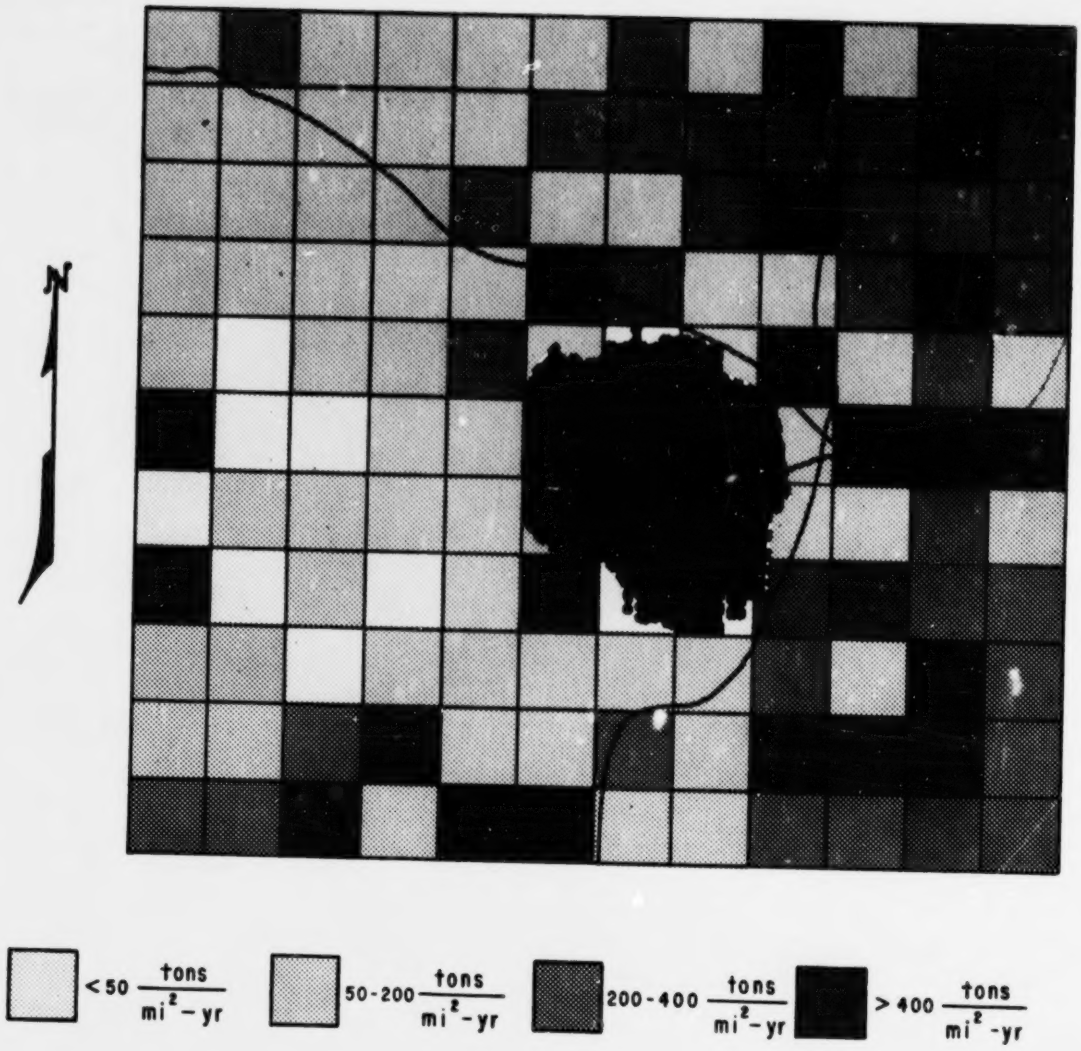

N
< 50 tons/mi²-yr
50-200 tons/mi²-yr
200-400 tons/mi²-yr
> 400 tons/mi²-yr

Fig. 5.11. Hydrocarbon Emission Densities from O'Hare Airport and the Surrounding Area

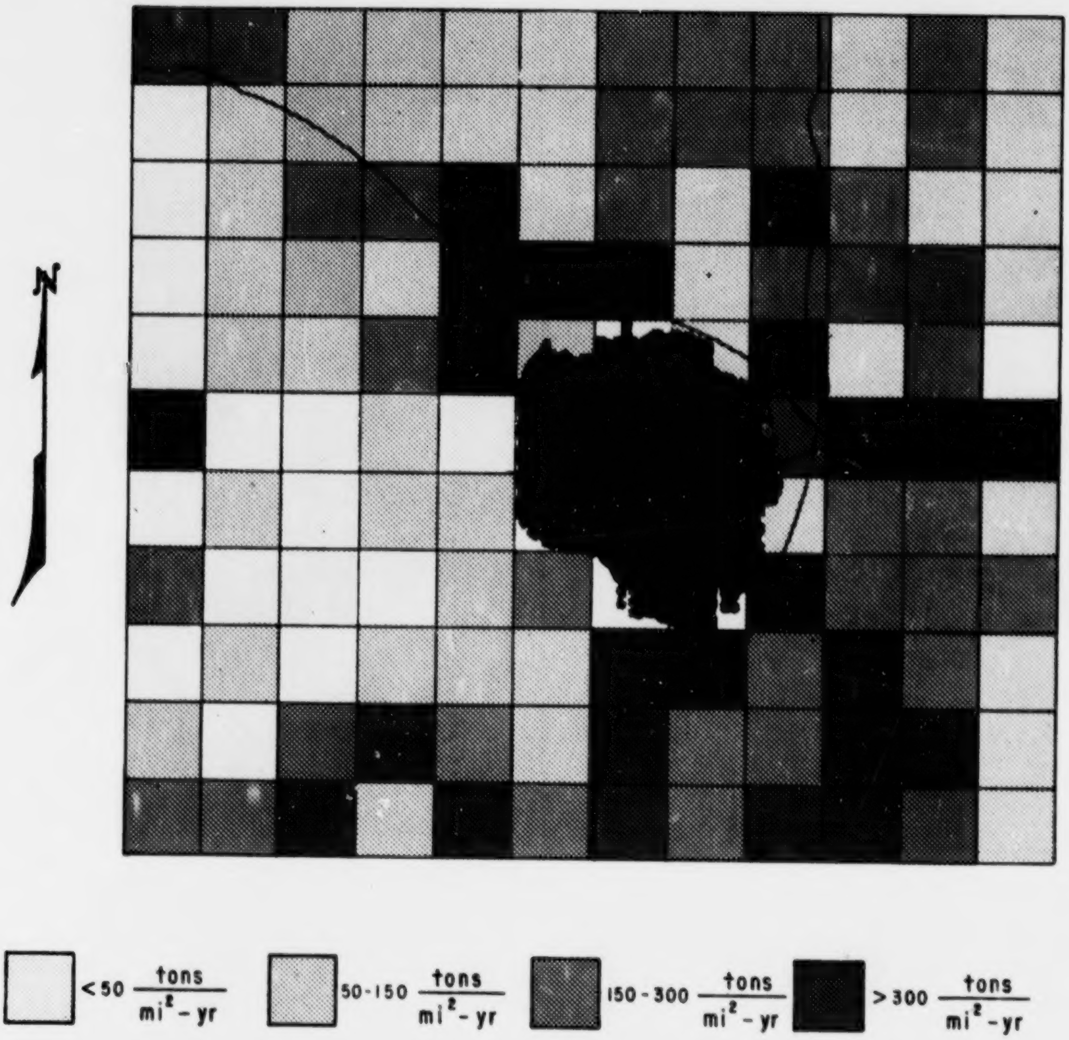

N
< 50 tons/mi² - yr
50 - 150 tons/mi² - yr
150 - 300 tons/mi² - yr
> 300 tons/mi² - yr

Fig. 5.12. Nitrogen Oxides Emission Densities from O'Hare Airport and the Surrounding Area

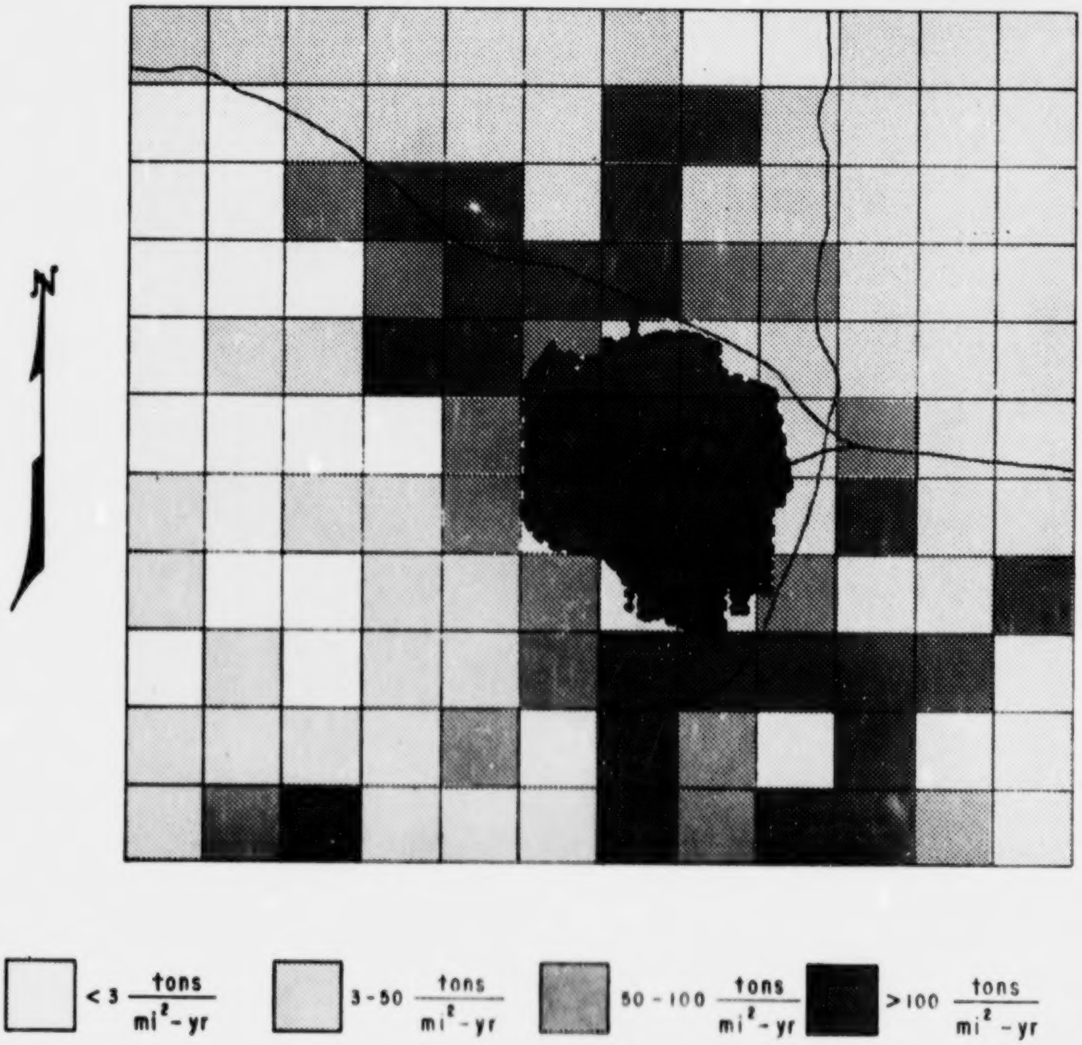

N
< 3 tons/mi²-yr
3-50 tons/mi²-yr
50-100 tons/mi²-yr
>100 tons/mi²-yr

Fig. 5.13. Particulate Emission Densities from O'Hare Airport and the Surrounding Area

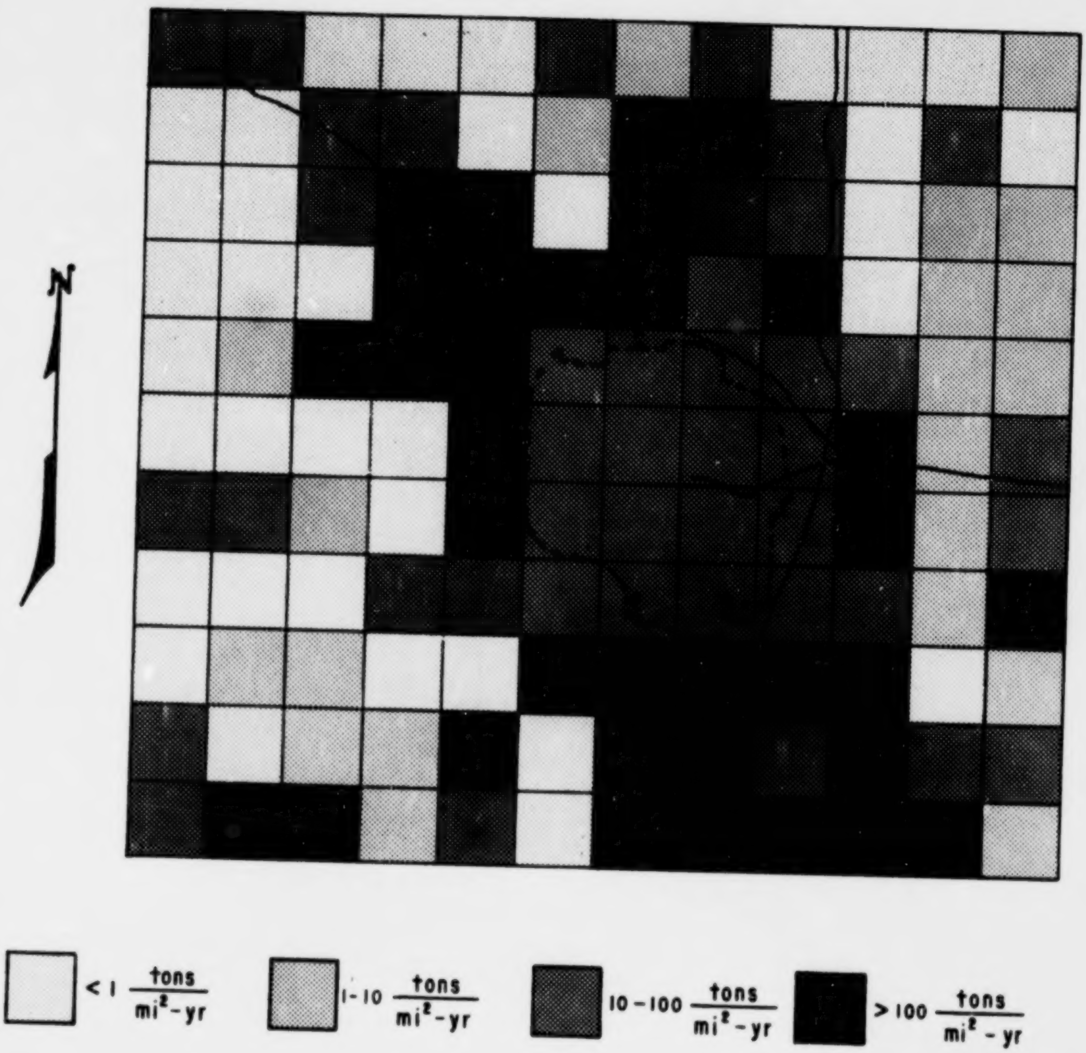

N
< 1 $\frac{\text{tons}}{\text{mi}^2\text{-yr}}$
1-10 $\frac{\text{tons}}{\text{mi}^2\text{-yr}}$
10-100 $\frac{\text{tons}}{\text{mi}^2\text{-yr}}$
> 100 $\frac{\text{tons}}{\text{mi}^2\text{-yr}}$

Fig. 5.14. Sulfur Dioxide Emission Densities from O'Hare Airport and the Surrounding Area

Table 5.10

1970 Emissions From 4 Townships Surrounding O'Hare (Tons/Yr.)

	Residential	Commercial	Manufacturing & Warehousing	Motor Vehicles	Total	Density* Tons/Mi^2-Yr.
SO_2	-	189	13,395	-	13,584	118
Part	142	75	7,998	560	8,775	76
CO	150	36	806	190,456	191,448	1,657
HC	59	38	909	30,966	31,972	276
NO_x	370	321	8,287	17,375	26,353	225

*based on 115 sq. mi. excluding airport

O'Hare Airport Emissions (Tons/Yr.)

	Aircraft	Ground Service Vehicles	Access Traffic	Heating Plants	Fuel Handling	Total	Density** Tons/Mi^2-Yr.
Part	542	23	34	511	-	1,110	112
CO	9,108	4,245	4,711	32	-	18,096	1,828
HC	5,377	942	821	32	582	7,754	783
NO_x	3,205	440	575	291	-	4,511	456

**based on 9.9 sq. mi. airport property

6.0 METEOROLOGICAL AND AIR POLLUTION POTENTIAL ANALYSIS

6.1 Introduction

This section presents a description of the regional meteorology and potential for high air pollutant buildup in the vicinity of the proposed St. Louis airport. Much of the data used for this analysis was derived from the National Weather Service at Lambert Field and through low level soundings taken at the Arch in downtown St. Louis. Additional data were derived from Scott Air Force Base, the State of Illinois Air Quality Annual Report and modeling results of the St. Louis region conducted by Argonne as part of the implementation plan for the State of Illinois. The objectives of this section are to:

1) Present meteorological data which can be used to evaluate air pollution potential.

2) Present existing measured air quality data in the airport vicinity.

3) Present existing modeling results which can be used to estimate the background levels in the proposed airport area due to metropolitan emissions.

6.2 Transport Wind and Mixing Height Climatology for the St. Louis Metropolitan Area

Two of the most important parameters governing the dispersion of air pollutants in the lower atmosphere are the transport wind and mixing height. A review of the historical data for these two parameters allows the assessment of the potential for air pollution buildup due to the emissions related to the porposed airport and its surrounding development. In this section the frequency of occurrence and persistence, of low wind speeds, as well as expected mixing heights and frequencies of poor ventilation are examined.

The St. Louis urban sounding data was gathered under the National Weather Service Environmental Support Unit (EMSU). This data was gathered from May, 1969 to April, 1971.[39] These soundings were taken twice daily near the center of the St. Louis Metropolitan Area at the Jefferson National Expansion Memorial Park. This is the site of the Gateway Arch and the immediate vicinity is bounded by the Mississippi River to the east and by a built-up central urban complex south through west to north. Normally, unless an air stagnation period extended into or began on a weekend, the soundings were only taken on weekdays. The times of release are near sunrise and near noon local standard time. In spite of these weekend discontinuities and other less frequent data breaks due to problems such as instrument failure, the available sample is large, and therefore, representative of the total population in any given year.

Definitions and Procedures

The mixing height is an approximation to the height of the top of the surface-based mixed layer through which (ideally) pollutants readily mix at some distance downstream of the sources.

The morning mixing height (MNHT) is a calculated, not an observed, mixing height. It is obtained in the following manner:

1) Add 3°C to the surface temperature of the sunrise sounding.

2) Extend a dry adiabat from this temperature to the sounding curve.

3) The above-ground height of this intersection is the morning mixing height.

This method is employed because of the difficulties involved with resolving shallow morning mixing depths with the existing instrumentation and evaluation procedures. The calculated height is a relative index of low-level stability and is normally representative of the urban mixing height in the first few hours after sunrise.

The midday mixing height (MXHT) is the "observed" mixing height obtained from the midday sounding as follows:

1) The height from the surface to the base of the lowest inversion or isothermal layer will be the observed mixing depth.

2) In the absence of any isothermal or inversion layer, the point at which the lapse rate becomes more stable than moist adiabatic will provide the mixing depth lid.

3) If a lid as described in 1) and 2) doesn't exist below the 700 mb level, the mixing depth will be considered unlimited (3000 meters, for this study).

The resultant transport wind (RTW) speed is obtained from the urban soundings in the following manner:

1) Establish the mixing height (observed or calculated).

2) Find the horizontal distance out (HDO) from the release point of the instrument package when it reached the mixing height.

3) Establish (from the radiosonde recorder) time elapsed (TE) from the release to mixing height intersection.

4) HDO divided by TE equals the resultant transport wind speed through the mixed layer.

Another parameter utilized in this climatology is the ventilation factor. This parameter, commonly used during midday or maximum dispersion periods, is a product of the mixing height and the transport wind speed. It is a measure of the volume rate of horizontal transport of air within the mixed layer per unit distance normal to the RTW vector.

Monthly Statistics

Tables 6.1 through 6.3 represent a summary of a two-year data sample of mixing heights, transport wind speeds, and midday ventilation. In each case, monthly means are presented together with the data count (N), the standard deviation, and the coefficient of variation (V). This latter parameter is the standard deviation divided by the sample mean X 100 is an indication of the relative scatter about the mean.

In all cases it is obvious from both V and the standard deviation that there is a substantial scatter in the monthly data sample, reducing the significance of the computed mean values. There is some doubt that the data samples are normally distributed, especially ventilation where V exceeds 100 on a number of months. This is not surprising since ventilation is the product of two other parameters with high scatter.

The monthly coefficient of variation V (relative scatter) shows little or no annual pattern during the early morning period for either MNHT or RTW speeds. This is also generally true of the midday parameter except for the lower V values for MXHT, RTW and ventilation during the summer months.

Since the calculated MNHT (Table 6.1) from the morning sounding is an index of low-level stability (increasing stability = decreasing MNHT), it has its lower values during the months that the low or ground level inversion has its highest frequency, i.e., July through September. Higher MNHT values tend to occur from over a longer period from November through March. March has the maximum value, possibly related to the transitional nature of the weather during that month. The annual maximum and minimum of mean morning

Table 6.1 - ST. LOUIS MORNING SOUNDINGS (500 cases)
METERS

Month	N	Mean MNHT	+ - Stand. Dev.	V	Mean RTW Speed	+ - Stand. Dev.	V
June	41	427	271	63	5.7	2.8	49
July	42	332	210	63	4.1	2.4	59
Aug.	43	297	215	72	4.0	2.3	58
Sept.	41	383	239	62	5.5	3.0	55
Oct.	45	438	314	72	6.6	3.1	47
Nov.	35	596	527	88	7.5	4.0	53
Dec.	39	547	260	48	6.9	3.0	43
Jan.	37	568	342	60	7.7	3.2	42
Feb.	35	533	344	65	7.9	3.2	41
March	43	699	404	58	8.1	4.7	58
April	42	473	303	64	7.5	3.4	45
May	57	420	291	69	6.8	3.6	53

MNHT = Morning Mixing Heights in Meters
RTW = Resultant Transport Wind Speed in Meters Per Second
V = Coefficient of Variation = $\frac{\text{Standard Deviation X 100}}{\text{Mean}}$

Table 6.2 - ST. LOUIS MIDDAY SOUNDINGS (448 cases)
METERS

Month	N	Mean MXHT	+ - Stand. Dev.	V	Mean RTW Speed	+ - Stand. Dev.	V
June	30	1407	627	45	5.5	2.4	44
July	43	1901	787	41	4.5	2.3	51
Aug.	41	1484	646	44	4.4	1.6	36
Sept.	37	1291	768	59	4.7	2.5	53
Oct.	39	1207	829	69	6.5	3.3	51
Nov.	32	935	492	53	6.1	3.3	54
Dec.	38	722	497	69	6.0	2.8	47
Jan.	37	715	486	68	6.6	3.8	58
Feb.	33	749	326	44	7.5	3.6	48
Mar.	37	1104	618	56	7.4	3.9	53
Apr.	43	1346	752	56	7.3	3.5	48
May	38	1436	708	49	7.1	3.4	48

MXHT = Midday Mixing Heights in Meters
RTW = Resultant Transport Wind Speed in Meters Per Second
V = Coefficient of Variation = $\frac{\text{Standard Deviation X 100}}{\text{Mean}}$

Table 6.3

St. Louis Midday Soundings

(448 cases)

Month	N	Mean Vent.	+ - Stand. Dev.	V
June	30	8296	6445	78
July	43	8944	6145	62
Aug.	41	6286	3438	55
Sept.	37	6475	6351	98
Oct.	39	9509	10752	113
Nov.	32	6289	5749	97
Dec.	38	4857	5840	120
Jan.	37	5566	6037	108
Feb.	33	6161	5269	86
Mar.	37	8313	7600	91
Apr.	43	10521	8665	82
May	38	10630	7504	71

Vent. - Ventilation $\left(\frac{\text{Meter}^2}{\text{Sec}}\right)$ = MXHT (meters) X RTW Speed (meters per second)

V = Coefficient of Variation = $\frac{\text{Standard Deviation X 100}}{\text{Mean}}$

RTW speeds occur in phase with the MNHT means. This is not surprising since the highest stabilities are generally associated with the lowest wind speeds.

This is in contrast to the midday parameters (Table 6.2), where the annual maximum and minimum of RTW speed and MXHT (observed) means are approximately 180° out of phase with each other. The annual variation of midday RTW speeds is about the same as the morning RTW speeds; however, the maximum average MXHT values tend to occur in the late spring and summer months with the peak mean value in July, the month where unlimited MXHT values are most frequent. The monthly MXHT means drop to a minimum in January. This trend is similar to and obviously related to the annual temperature curve and the lagged solar radiation curve.

The midday ventilation means (Table 6.3) begin to give some insight on air stagnation potential in spite of the high scatter. Two important minima in the monthly means occur during the year. One is in August, when MXHT values are decreasing from the July maximum faster than the winds are increasing from the summer minimum. The second minimum is more pronounced, with the lowest ventilation month of the year being December. The first minimum (August) is most frequently a result of low RTW speeds as opposed to the cold season minimum which is more frequently associated with low MXHT values. (Note that the mean ventilation values used in this study are the averages of the daily values of ventilation and not the product of the mean RTW and mean MXHT).

In Fig. 6.1 the data are stratified to exclude all data points with ventilation >6000 m^2ps and transport wind speeds >4.0 mps. These values coincide with the threshold levels for air stagnation in the National Meteorological Center's forecast program. The ordinate of

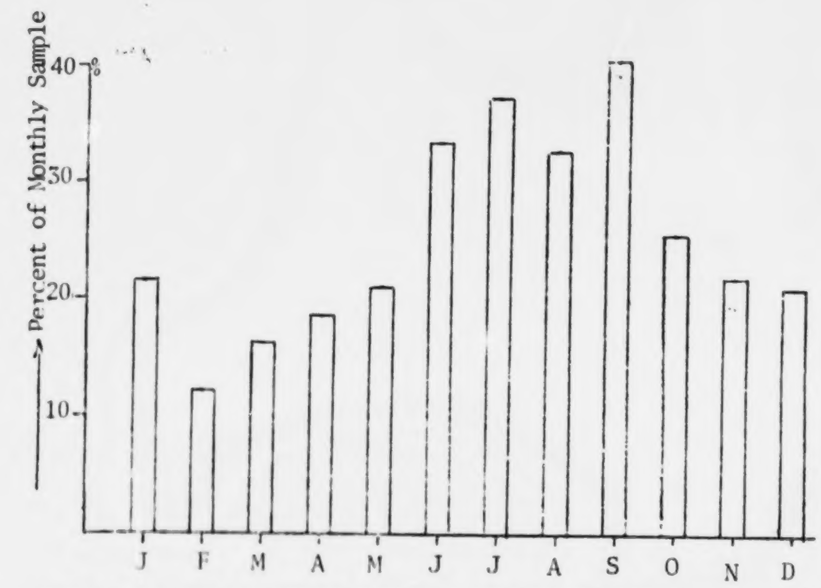


FIG.6.1- MONTHLY FREQUENCY DISTRIBUTION OF MIDDAY STAGNATION-ST. LOUIS, MO. CRITERIA: RTW SPEED ≤4.0 MPS AND VENTILATION ≤6000 M^{2}PS... ORDINATE IS % OF THE MONTHLY SAMPLE BASED ON 2 YEARS OF DATA

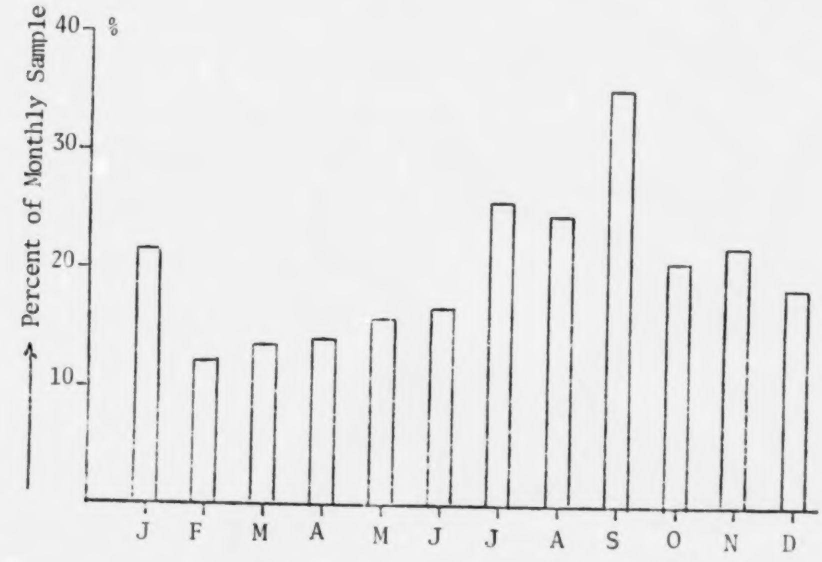


FIG. 6.2 - SAME AS FIG. 1 BUT VENTILATION ≤4000 M^{2}PS

Fig. 6.1 is the percentage of the monthly data count (N in Table 6.3) for which midday ventilation was $\leq 6000\ m^2ps$ and the associated RTW speed was ≤ 4.0 mps. The higher frequencies of this condition are during the summer and early fall months (June through September) with September having the peak monthly frequency. There seems to be a weak secondary rise in January just before lowest monthly frequency in February, but this could easily be due to the small sample size.

In Fig. 6.2 the same stratification was applied except that the ventilation threshold was lowered to $<4000\ m^2ps$. The basic pattern from Fig. 6.1 to Fig. 6.2 does not change, but June is eliminated from the clear summer maximum.

To date, since the beginning of air stagnation advisory (ASA) services in the St. Louis Metropolitan Area in 1968, there have been five advisories issued. Two of these have occurred in August (1969 and 1971) and one each in January 1969, November 1969, and December 1971. Although September is indicated as the peak frequency times for midday stagnation, no advisories have yet been issued during that month. It should be remembered that air stagnation advisories normally have a duration requirement (36 hours or more) as well as a minimum dispersion criteria (normally early morning). Perhaps the reason for the higher frequency of advisories in August may be related to the lesser scatter about the monthly means of both ventilation and RTW speed. The standard deviation and coefficient of variation (V) are at their minimum (Tables 6.2 and 6.3) in the month of August, which would tend to support a higher probability that the midday stagnation days would be consecutive, and therefore, meet the ASA duration criterion. The sample of ASA occurrences is too small, however, to give any conclusive results. The very fact that midday stagnation frequency is at its maximum in July through September, and the morning calculated mixing heights (MNHT) and transport wind speed monthly averages are at their minimum for the same period, would isolate the July through September period as the annual maximum for air stagnation potential.

Directional-Frequency Distributions and Means

This analysis of the sounding data involves only the midday soundings, and is a presentation of directional frequency. The total data count is 448 which the 5 log N rule would allow, roughly, a maximum of 13 directional frequency classes. As a result, 30° direction increments were chosen, allowing 12 classes beginning with 0°. Table 6.4 presents the annual distribution together with average RTW speeds, MXHT and ventilation for each direction class; Figure 6.3 presents these data in a frequency direction rose. The RTW direction frequency distribution indicated in Table 6.4 and Fig. 6.3 agrees closely with the distribution of hourly surface wind observations at Lambert Field from the period 1951 to 1960 (Table 6.5). In both cases, annual maxima are from the south and northwest, with a minimum frequency from the east. The slight differences that do exist can most likely be assigned to the differences in direction categories and the fact that RTW is a vector average through a layer at midday, while the Lambert Field winds are surface winds from hourly observations. The latter effect results in generally higher average speeds from the RTW. The variation of average speeds with direction is also similar to the surface wind distribution. In general, from Table 6.4 it is obvious that the RTW directions with easterly components have lower average RTW speeds, MXHTs and ventilation factors. Only a couple of cases of MXHTs and RTW speed averages depart from this generality.

Table 6.4

St. Louis Midday Soundings - Frequency Directional Distribution

	360-29°	30-59°	60-89°	90-119°	120-149°	150-179°	180-209°	210-239°	240-269°	270-299°	300-329°	330-359°
N	28	23	20	13	19	54	62	47	44	59	44	34
% Total	6.3	5.1	4.5	2.9	4.2	12.1	13.8	10.5	9.8	13.2	9.8	7.6
Mean RTW Speed	6.1	3.6	4.8	5.4	4.7	5.0	7.6	6.1	6.9	7.1	6.7	5.4
Mean MXHT	881	1529	1194	928	1013	968	1279	1383	1435	1340	1205	1173
Mean Vent.	5509	4275	5812	4180	4878	5066	9565	8958	10829	9665	8652	7012

Total Data Count = 448

MXHT - Observed Midday Mixing Height (Meters)

RTW = Resultant Transport Wind Speed (meters per second)

Ventilation = MXHT X RTW Speed $\left(\frac{\text{meters}^2}{\text{sec}}\right)$

Table 6.5

St. Louis surface winds (St. Louis-Lambert Intl. Airport)
Annual Directional Distribution
Summary of Hourly Observations (WBAN) 1951 - 1960

Dir.	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	Calm
% Total	4.5	3.2	3.9	3.2	3.9	5.2	7.0	7.6	10.8	6.2	6.3	5.0	6.2	8.4	9.4	5.3	3.8
Avg. Speed m.p.s.	3.8	3.6	3.5	3.8	4.1	3.9	4.2	5.0	4.6	4.3	4.0	4.4	4.4	4.9	4.7	4.3	

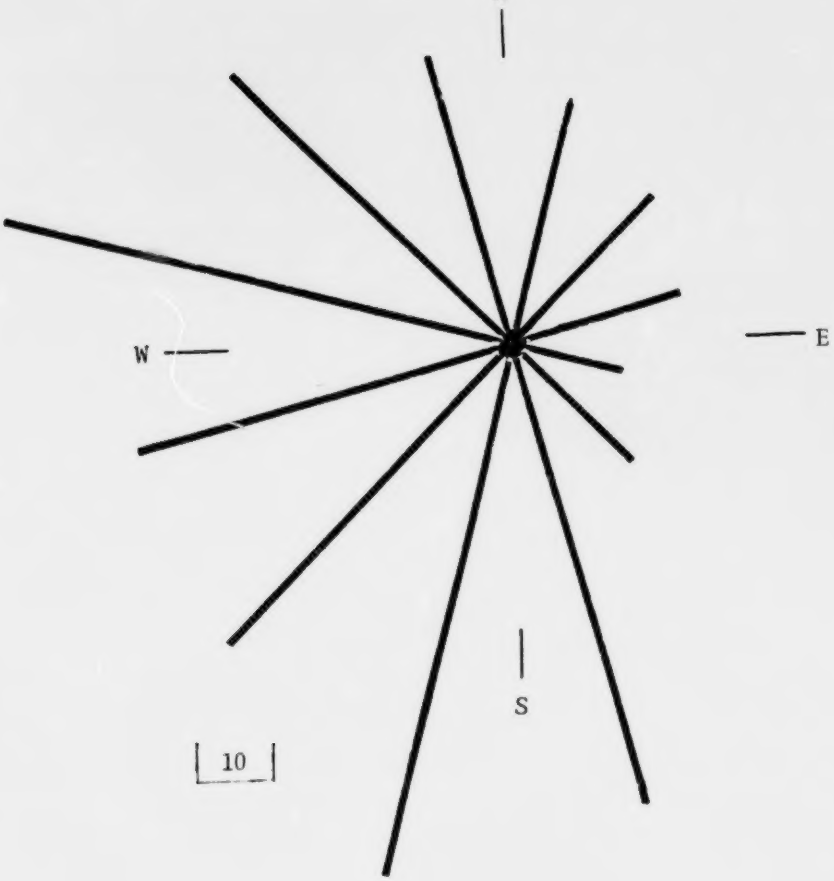


Fig. 6.3 Resultant Transport Wind Rose - Annual St. Louis Midday Urban Soundings
Direction Class Size = 30°
Based on a 2-Year Sample
with N = 448
(1 calm)

Figure 6.4 presents the base data stratified as in Fig. 6.2, i.e., all data points (midday soundings) with RTW ≥4.0 mps and ventilation ≥4000 m^2ps have been removed, leaving only cases of well-defined midday stagnation. The difference is that Fig. 6.2 is categorized by months and Fig. 6.4 utilizes 30° directional classes. It is obvious from Fig. 6.4 that the south-southeast class (150-179°) has the highest frequency of midday stagnation. This category is also the third highest direction frequency in the total two-year data count (Table 6.4, Fig. 6.3). This is significant when one considers the fact that the first and second highest frequency class from Table 6.4, 180-209° and 270-299°, respectively, have a relatively low frequency of midday stagnation on Fig. 6.4. To check on the extent to which the location or magnitude of the primary maximum and minimum of Fig. 6.4 was dependent upon the arbitrary choice of the center of the interval, the data were put into overlapping 30° intervals based on the 10° interval of the basic data. There was no significant change from the indication of Fig. 6.4.

A seasonal RTW direction-frequency distribution breakdown was also made as the basis of the two-year sample of midday soundings. The results of this breakdown are presented in the form of frequency-direction distributions (wind roses) in Fig. 6.6. The seasonal breakdown is by 3-month intervals, i.e., Winter - December through February; Spring - March through May, etc. The directional classes are the same as in Fig. 6.3, 6.4, and 6.5, i.e., 30° intervals. However, one point stands out; namely, the minimum generally associated with the easterly component directional categories is not prominent in summer.

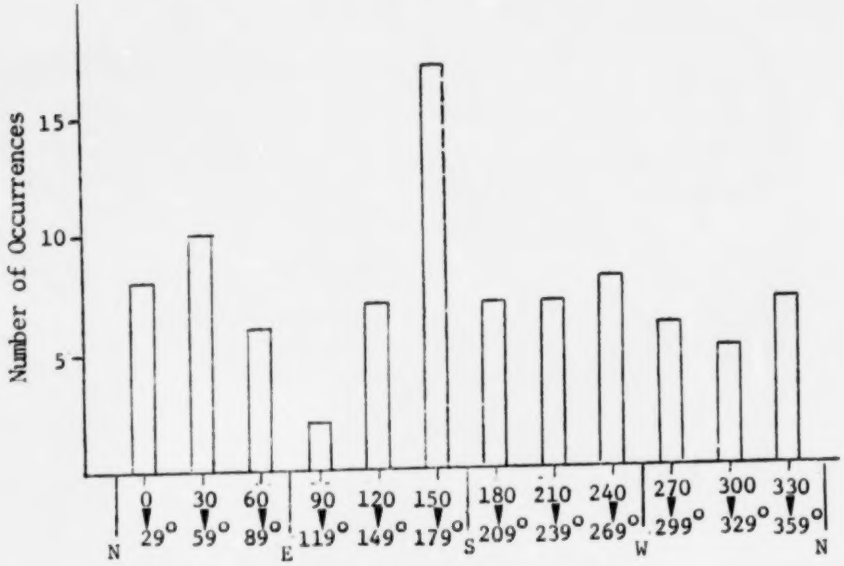


FIG. 6.4-DIRECTIONAL DISTRIBUTION OF MIDDAY STAGNATION.

CRITERIA: RTW SPEED ≤4.0 MPS AND VENTILATION ≤4000 M^2PS (90 CASES-20.1%)

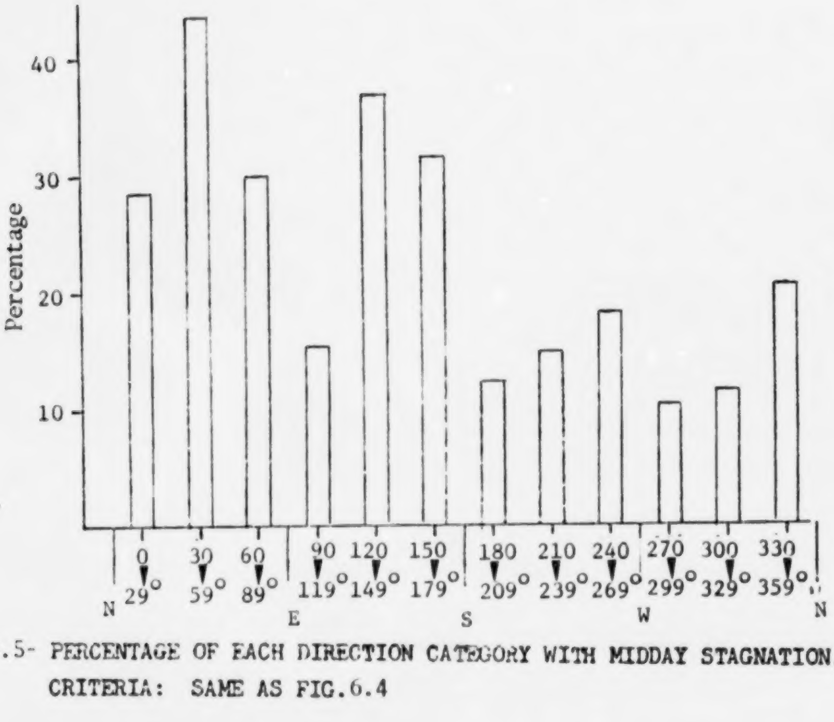


FIG. 6.5- PERCENTAGE OF EACH DIRECTION CATEGORY WITH MIDDAY STAGNATION.
CRITERIA: SAME AS FIG. 6.4

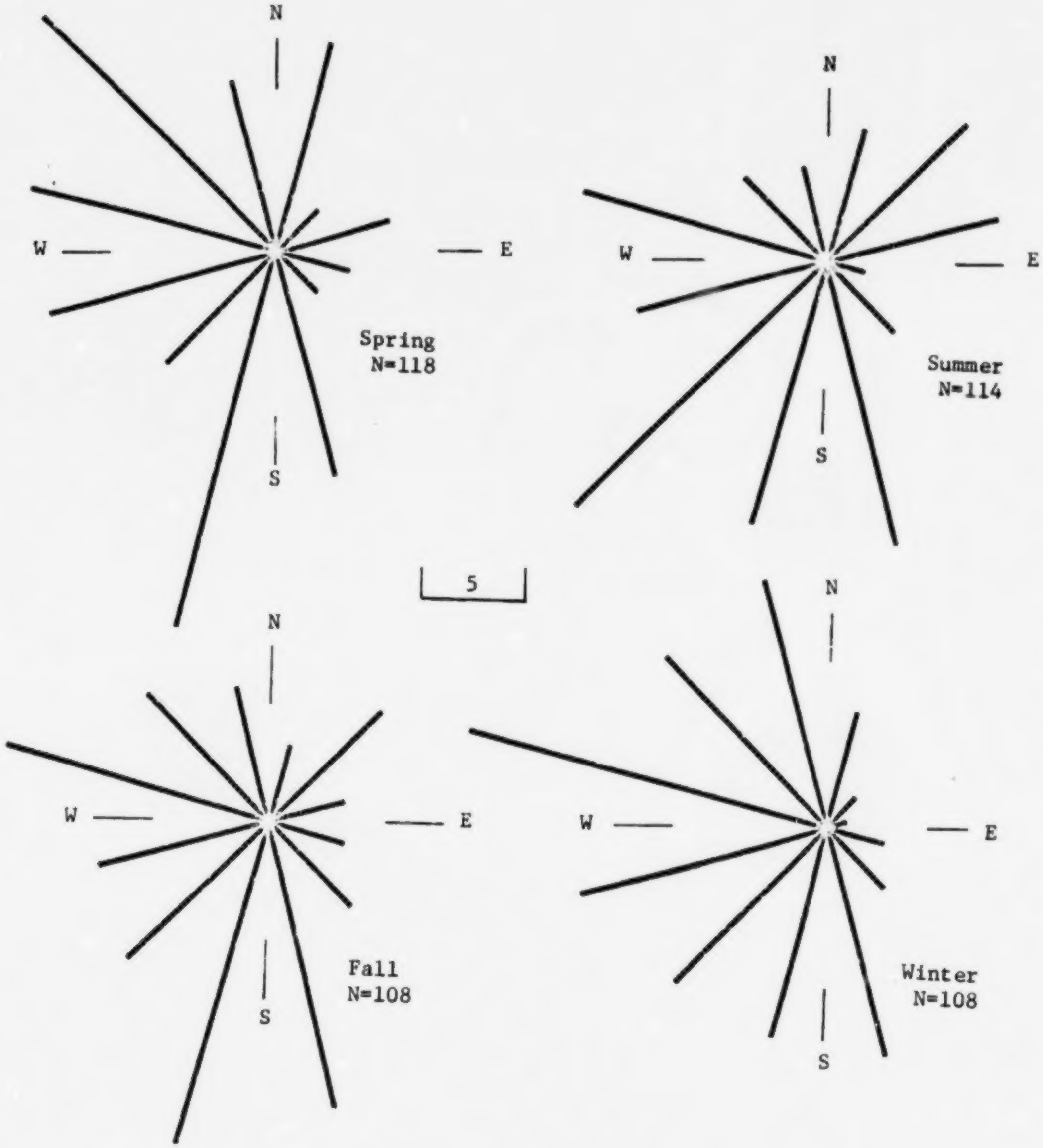


Fig. 6.6 - Resultant Transport Wind Roses

TABLE 6.6

LOW WIND SPEED PERSISTENCE TABLE FOR SCOTT AIR FORCE BASE (1/1/59 - 12/31/68)

Stability Class	Wind Speed (mph)	1 Hour Duration		2 - 12 Hour Duration	
		Number of Events	Percent of Total Hours	Number of Events	Percent of Total Hours
1 - 3	0 - 4	3635	5.3	269	0.8
1 - 3	5 - 7	4589	66.6	485	1.4
4 - 5	0 - 4	6254	8.9	1335	4.6
4 - 5	5 - 7	10461	15.1	2594	9.2

Total Time in Hours = 69417

LOW WIND SPEED PERSISTENCE TABLE FOR LAMBERT FIELD (1/1/55 - 12/31/70)

Stability Class	Wind Speed (mph)	1 Hour Duration		2 - 12 Hour Duration	
		Number of Events	Percent of Total Hours	Number of Events	Percent of Total Hours
1 - 3	0 - 4	1586	1.5	51	0.1
1 - 3	5 - 7	4681	4.4	239	0.6
4 - 5	0 - 4	3505	3.3	453	9.69.6
4 - 5	5 - 7	16063	15.2	3102	7.0

Total Time in Hours = 105430

Low Wind Speed Persistence

A climatology computer program prepared by the Argonne Center for Environmental Studies was used to scan weather data from Lambert Field (1/1/55 to 12/31/70) and Scott Air Force Base (1/1/59 to 12/31/68) in order to produce frequency distributions of low wind speed persistence. The data was grouped by wind speed bands (0 - 4 m.p.h. and 5 - 7 m.p.h.), atmospheric stability (stable air; class 4 - 5, unstable air; 1 - 3), and wind speed persistence. This division by persistence produces the frequency of long duration low wind speeds which are a strong contributing factor in pollutant build-ups. The results are presented in Table 6.6.

The analysis indicated that no low wind speeds persisted greater than twelve hours in the 0 - 4 m.p.h. band or the 5 - 7 m.p.h. band for either Scott or Lambert Field data. Comparing the Scott and Lambert data (as they are on opposite sides of the Mississippi and are separated by approximately thirty miles), low wind speed occurrences are generally similar in the St. Louis area, although for stable air in the 0 - 4 m.p.h. band there is about twice the probability of having a 2 - 12 hour persistence at Lambert Field.

6.3 Existing Air Quality Data in the Proposed Airport Vicinity

An important component in the preparation of environmental impact analyses for a major airport should be the establishment of baseline air quality levels in the proposed airport vicinity. In the case of the proposed St. Louis airport at Waterloo/Columbia, Illinois, air quality data has been derived from the Annual Air Quality Report published by the State of Illinois. Air quality data in the area southeast of the city of St. Louis is quite limited with only one monitoring site in the immediate vicinity of the proposed airport; this site being at Columbia, Illinois.

Illinois' annual air quality report indicates five sites in the area southeast of St. Louis (see Fig. 6.5). The monitors at each of these sites measure SO_2 and/or suspended particulates, many of these measure SO_2 through the use of the lead candle sulfation technique which is, at best, a crude indication of sulfur dioxide concentrations and trends. The existing data for the region, going back several years in time, is shown in Table 6.7. At the Columbia site, there exists a high volume particulate sampler which indicates data from 1969, 1970 and 1971. The measurements show a relatively constant value of particulates with a peak of 86 in 1970. The primary federal air quality standards for particulate matter is 75 micrograms per cubic meter and the secondary standard is 60 micrograms per cubic meter. Therefore, the air quality in the airport vicinity based on this one sampler is approximately equal to the primary standard at the current time. Additional particulates may cause degradation to occur in excess of the primary standards. This monitor, however, could be indicative of local sources in the Columbia area. The precise location with respect to nearby particulate sources is unknown.

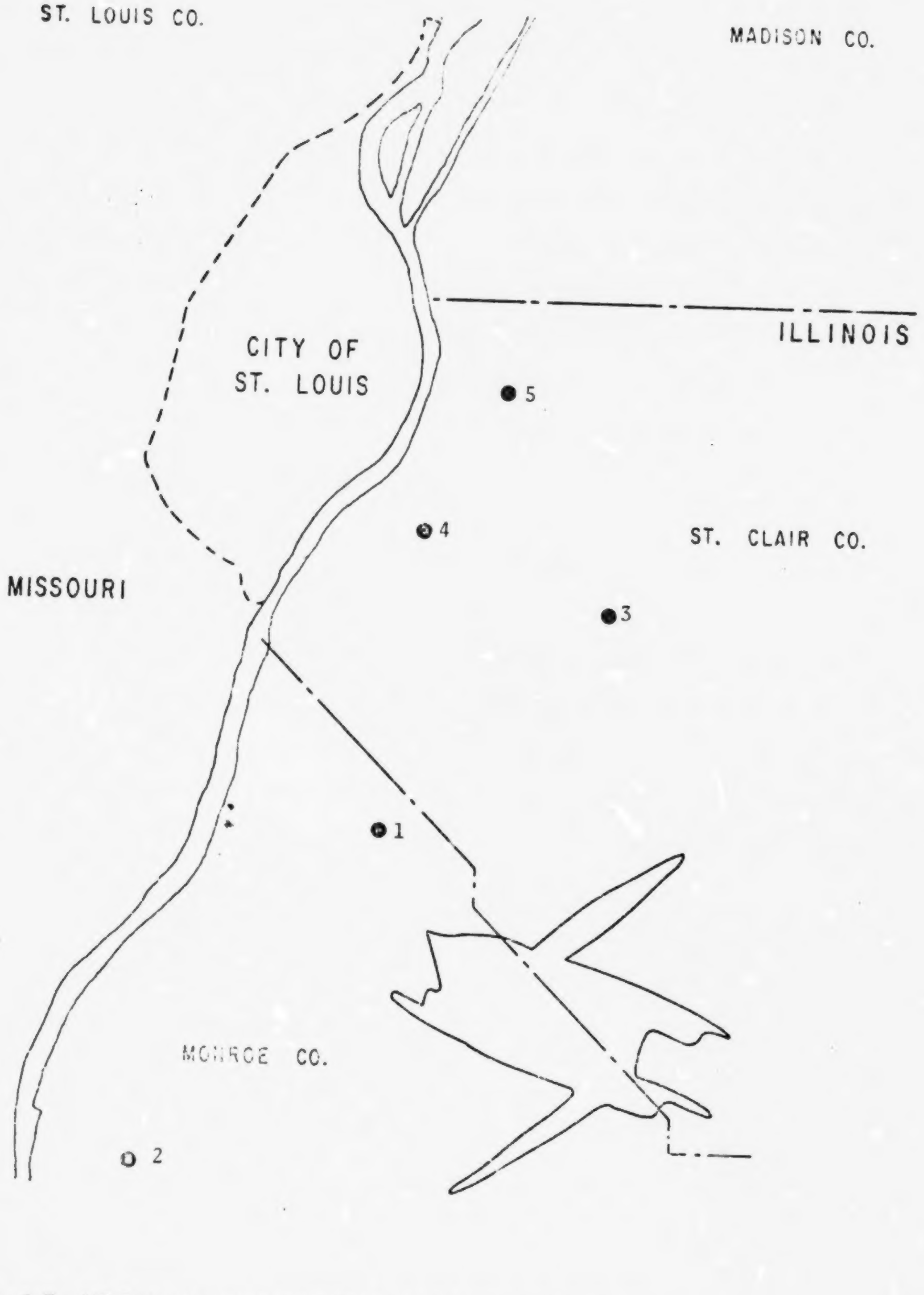

ST. LOUIS CO.
MADISON CO.
ILLINOIS
CITY OF ST. LOUIS
5
4
ST. CLAIR CO.
MISSOURI
3
1
MONROE CO.
2

FIG. 6.7 AIR QUALITY MONITORING STATIONS IN THE PROPOSED AIRPORT REGION

Table 6.7

Measured Air Quality in the Proposed Airport Vicinity

Suspended Particulates - High volume data
μ/m^3 (annual geometric mean)

	Site	1967	1968	1969	1970	1971
(1)	Columbia	XX	XX	70	86	72
(3)	Belleville	XX	XX	83	90	84
(5)	E. St. Louis	150	140	130	112	105

Lead Dioxide Candle Sulfation Data
Milligrams of SO_3 per 100 square centimeters per day (annual arithmetic average)

Numbers in parentheses are ppm*

		1967	1968	1969	1970	1971
(1)	Columbia	XX	XX	.25 (.01)	.24 (.010)	.33 (.013)
(2)	Harrisonville	XX	XX	.28 (.011)	.21 (.008)	.26 (.010)
(3)	Belleville	XX	XX	.32 (.013)	.39 (.016)	.41 (.016)
(4)	Cahokia	XX	XX	.47 (.019)	.43 (.017)	.43 (.017)
(5)	E. St. Louis	1.39 (.056)	1.45 (.058)	1.01 (.04)	.91 (.036)	.85 (.034)

SO_2 Bubbler Data (ppm)

		1967	1968	1969	1970	1971
(5)	E. St. Louis	XX	.04	.038	.015	.021

*Level candle data has been converted to ppm annual averages using the conversion: mg per 100 cm^2 per day x .04 = ppm. This is a rough approximation taken from Stern.[x4]

Sulfation data from the Columbia station indicates a constant level of sulfation from 1969 to 1970 with an increase in 1971 to .013 ppm. These values assume a crude approximation for the conversion of sulfation rates to parts per million. On this basis, the sulfur dioxide in Columbia is less than both the primary standard (.03 ppm) and the secondary standard (.02 ppm). It is not likely that the airport emissions will affect the levels since little SO_2 is emitted unless there are stationary heating plants using high sulfur coal or oil. However, the land use study in the vicinity of O'Hare has indicated significant increases in SO_2 due to industrial development in that vicinity. Therefore serious consideration should be given to the sulfur dioxide air quality levels in the Columbia/Waterloo site.

6.4 Dispersion Model Air Quality Estimates

As part of the implementation plan submitted by the State of Illinois, Argonne prepared modeling analyses for sulfur dioxide and particulates in the St. Louis metropolitan area.[41] These analyses were based upon emission inventories collected by both Missouri and Illinois agencies and, in addition, include the expected impact of the proposed 1975 regulated air quality levels. Specific computer runs were performed to estimate levels of SO_2 and particulates in the proposed airport area due to the emissions from the metropolitan area. The results of these analyses are shown in Figs. 6.8-6.11.

Figure 6.8 shows the predicted particulate air quality levels based on the existing 1968 emission inventory. This figure shows that, aside from local effects, the background levels due to sources in the St. Louis area contribute approximately 5 to 10 micrograms per cubic meter in the airport vicinity. This is based on the assumption that the natural background level is

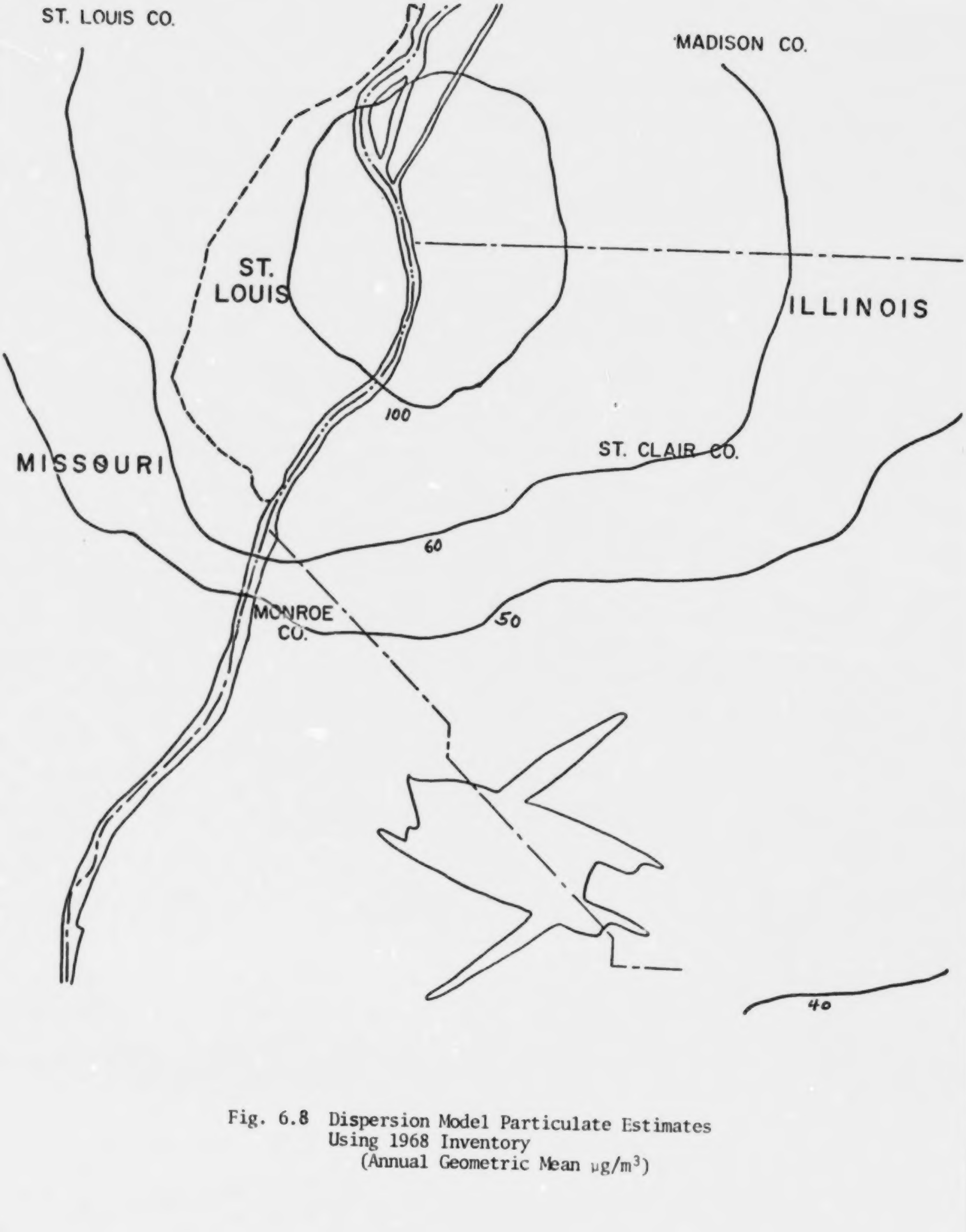
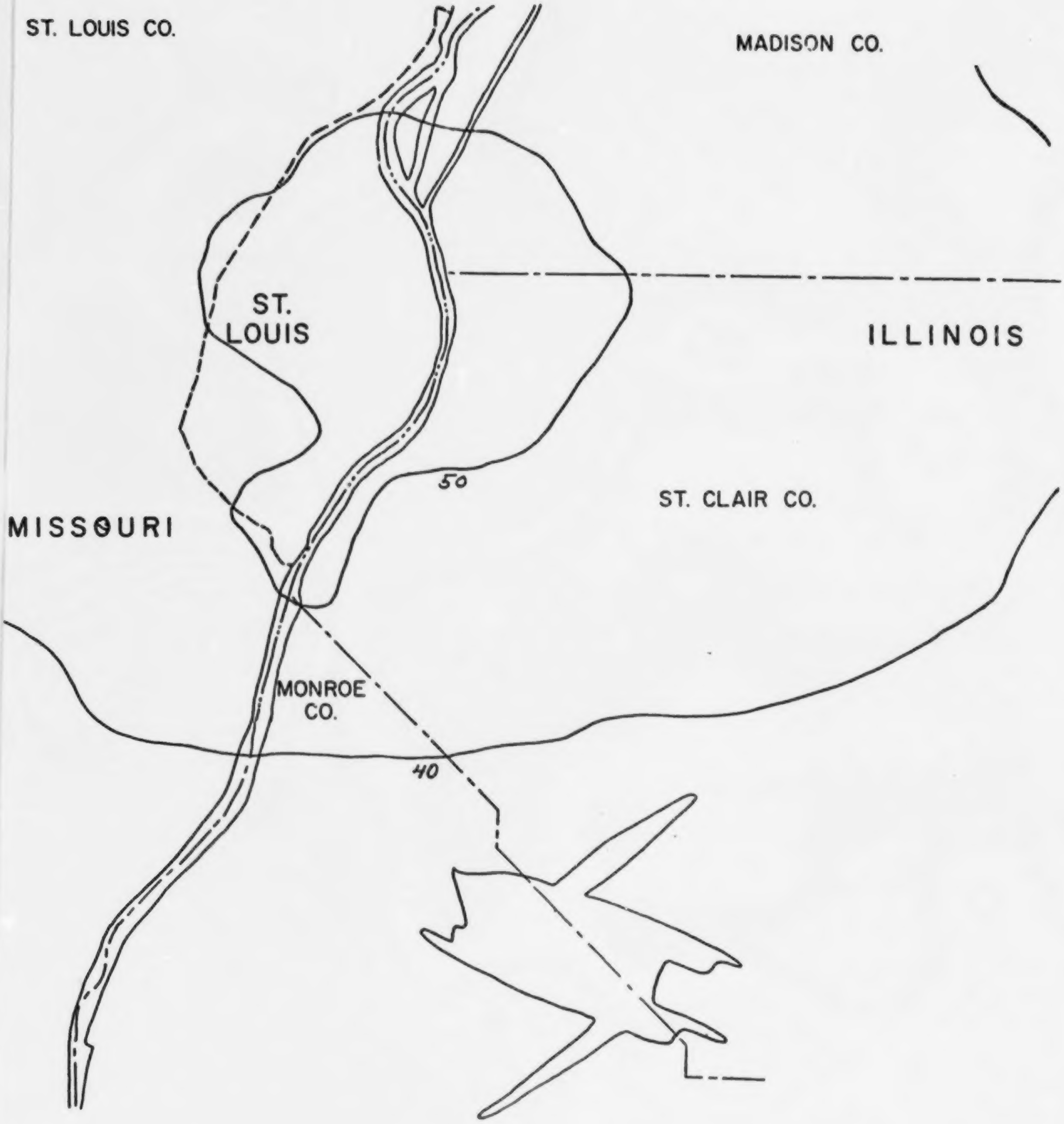

ST. LOUIS CO.
MADISON CO.
ST. LOUIS
ILLINOIS
100
MISSOURI
ST. CLAIR CO.
60
MONROE CO.
50
40

Fig. 6.8 Dispersion Model Particulate Estimates Using 1968 Inventory (Annual Geometric Mean $\mu g/m^3$)

40 μg/m^3. This value was used consistently in the strategy analysis for the State of Illinois. Figure 6.9 shows the 1975 projected impact if the proposed Illinois and Missouri regulations are achieved. The 40 μg/m^3 isopleth has receded to an area midway between the City of St. Louis and the airport site, indicating that the metropolitan area no longer contributes to particulate levels above the natural background in the proposed airport site vicinity.

The calculated sulfur dioxide levels in the airport area, using the 1968 inventory, are approximately 10 micrograms per cubic meter (see Fig. 6.10); considerably lower than the secondary standard (60 μg/m^3). In 1975, it is expected that these levels will decrease (Fig.6.11); however, as mentioned above, industry in the vicinity of the airport may contribute significantly to SO_2 levels, particularly since this is in a coal bearing region where the use of this fuel is common. Even the use of 1% sulfur coal in large quantities by clustered industry may significantly deteriorate the air quality.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ILLINOIS
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ST. CLAIR CO.
MISSOURI
MONROE CO.
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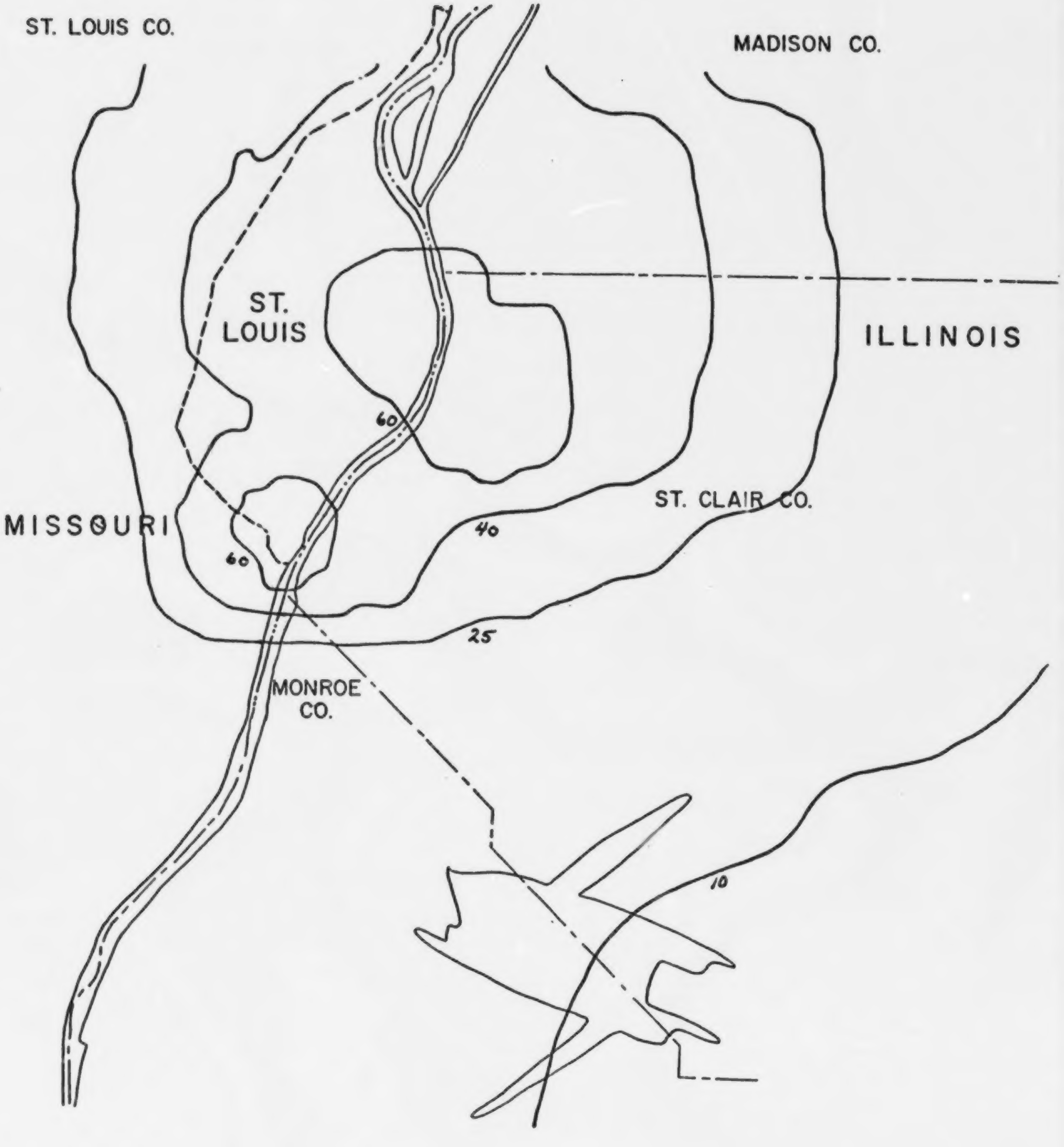
Fig. 6.9 Dispersion Model Particulate Estimates Based on 1975 Implementation Plan Regulations (Annual Geometric Means (Annual Geometric Means $\mu g/m^3$)


ST. LOUIS CO.
MADISON CO.
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ILLINOIS
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MISSOURI
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ST. CLAIR CO.
25
MONROE CO.
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Fig. 6.10-Dispersion Model SO_2 Estimates Using 1968 Inventory (Annual Arithmetic Mean $\mu g/m^3$)

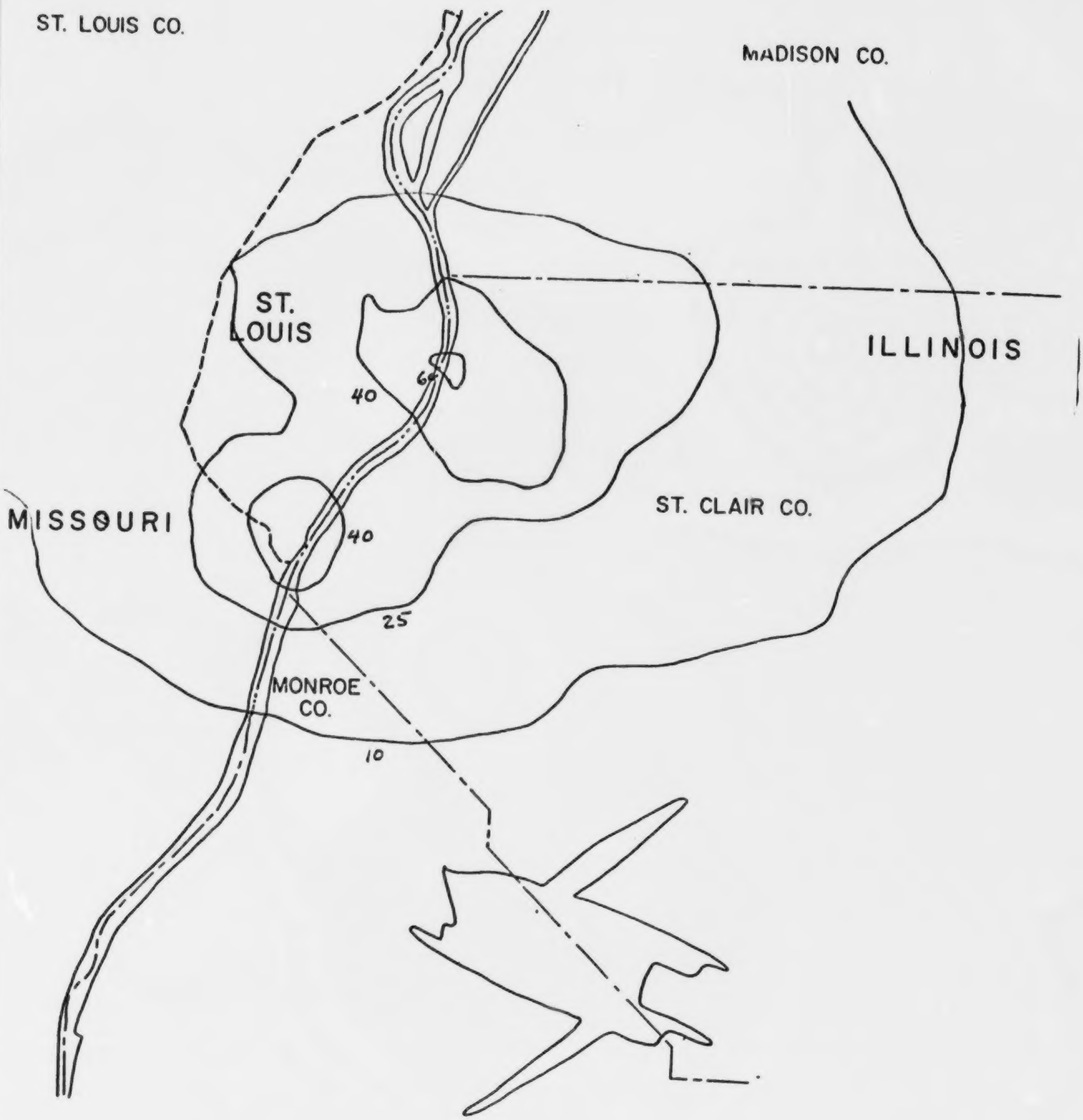
ST. LOUIS CO.
MADISON CO.
ST. LOUIS
ILLINOIS
40
60
MISSOURI
40
ST. CLAIR CO.
25
MONROE CO.
10

Fig. 6.11 - Dispersion Model SO_2 Estimates Based on 1975 Implementation Plan Regulations (Annual Arithmetic Mean μg/m^3)

7.0 AIR QUALITY MODEL ADAPTATIONS

As alluded to in previous sections, the next step in developing an air pollution analysis for airports is to transform the computed emission rates into air quality forecasts via dispersion modeling or some other technique. At present, there are three dispersion models including one photochemical model available at Argonne for use in computing airport air quality. They are the FAA/Argonne Airport Air Pollution Model, the Northern Research and Engineering Corp. (NREC) Model, and the Systems, Science and Software (S^3) photochemical model. This section will outline the steps necessary to prepare the already computed data for input into these models. A modified version of the NREC model is being prepared by Geomet, Inc.;[46] however, data on this work was unavailable at the time of this report.

7.1 FAA/Argonne Airport Air Pollution Model

This model of airport air pollution has been developed by Argonne for the Federal Aviation Administration[10] and is made up of two sub-models. The first deals with the simulation of airport activity and generates an emission inventory that is diurnally and spatially distributed. The second uses the emission inventory as a data base for computing air quality, using a modified steady-state gaussian plume algorithm. This particular algorithm has been developed and extensively validated at Argonne.

Portions of the activity sub-model have been used in this study to compute aircraft and ground service vehicle emission rates. Additional portions were adapted to compute emissions from other sources. Adjustments were necessary to reflect the fact that the model was initially developed to operate from a data base of observed information at an existing airport. The current application to the proposed new St. Louis airport meant that the same resolutions of the output data could not be made, due to the lack of information. The primary loss in this case is the spatial distribution of emissions. This could not be determined because the airport master plan has not yet been drawn up. Once this is available, however, the full output of the activity model can be utilized.

The activity sub-model further classifies the emissions by the type of source producing them. Emissions which are generated over a large area (e.g., ground service activity in the terminal area, automobile movement in the parking lots, fuel evaporation from the filling of vehicle tanks, etc.) are classified as area sources. Emissions generated in a long and narrow strip (e.g., roadways, runways) are classified as line sources. Emissions emanating from a very small area (e. g., heating plant, engine test cells) are classified as point sources. While this classification can be made for the St. Louis data, it is not possible to determine the dimensions and coordinates of these source types because of the aforementioned lack of spatial data.

It should be pointed out that even without the airport master plan, a first order approximation of spatial distribution could be made and the air quality calculations carried out on this basis.

The gaussian plume air quality sub-model utilizes the point, area, and line source parameters calculated by the activity sub-model, and combines them with meteorological information that is relevant to the area to compute air quality. Since the input emission inventory is both spatially and diurnally distributed, the resulting air quality is also spatially and diurnally distributed.

The sub-model uses a one-hour averaging time to compute pollutant concentrations and makes use of time- and distance-dependent dispersion coefficients. These give better results at the high and low ends of the wind speed range than the coefficients that are distance-dependent only. In addition, a diurnal variation of important meteorological parameters, such as wind speed, mixing depth, etc., is used instead of a seasonal average to improve the model's accuracy.

In making the computations the model extrapolates the point, area, and line sources back to a virtual origin. This eliminates some of the wide fluctuations in calculated concentrations resulting from changes in the wind direction-receptor location, referred to as the beacon effect.

To summarize, the projected emission rates can readily be translated into air quality via the FAA/Argonne Air Pollution Model. The data as presented needs only to be modified to show spatial distribution in order to serve as direct input into the air quality sub-model. Experience with this model on Chicago's O'Hare Airport shows the calculated air quality to be underestimated, as compared to observed air quality, particularly for hydrocarbon concentrations.

7.2 Northern Research and Engineering Corp. Model

The NREC model was developed for the Environmental Protection Agency[29] and is fundamentally similar to the FAA/Argonne model. An activity sub-model and an air quality sub-model are used.

The basic differences between the Argonne and the NREC air quality sub-models are the type of mathematical simplifications used to compute dispersion. The NREC model uses a one-hour averaging time and a gaussian plume algorithm, as does the Argonne model. NREC, however, uses only point sources that are located at ground level, instead of the virtual origin point, area, and line sources. It therefore suffers from the large fluctuations in concentration resulting from the beacon effect. Also, the NREC model uses a dispersion coefficients that are distance-dependent only.

As with the Argonne model, the emission calculations can be readily adapted for input into the NREC model once some spatial resolution is available. Experience with this model at Argonne has shown that it also underestimates air quality as compared to observations. In most cases, the discrepancies are larger than that of the Argonne model.

7.3 Systems, Science and Software Photochemical Model

The photochemical modeling portion of the air quality computations is based upon a package written by Systems, Science and Software (S^3).[42] It consists of two computer codes; the first, SETUP, uses meteorological and source data to create an input tape for the second, NEXUS/P (Numerical EXamination of Urban Smog with Photochemistry). NEXUS/P then moves and diffuses the pollutants, changes the pollutant concentrations as a result of photochemical reactions, adds pollutants due to sources, and stores or retrieves pollutants advected into or out of the borders of the computational grid.

The program was originally written to simulate the photochemical reactions taking place in the Los Angeles smog. It is, therefore, necessary to tailor SETUP to the conditions found around the airport under study.

The data read in at execution time includes wind measurements and initial concentrations of hydrocarbons, NO, NO_2, and CO if desired. NEXUS/P considers reactions occurring between and producing NO, NO_2, HC, O_3, and HNO_2. HNO_2 and O_3 are the results of photochemical reactions, while CO is not explicitly considered. Table 7.1 shows the reactions treated. Briefly, the S^3 model treats the transport of pollutants by assigning mathematical points to given amounts of pollutant. The movements of each of these points are then traced through time so that at any point in time and in any cell of the three-dimensional grid system the concentration can be determined by simply counting the number of points residing in that cell at that time. The mechanism for moving the points which takes into account both advection and diffusion is

Table 7.1

Rate Coefficients for Expanded Model of the Hydrocarbon/Nitric Oxide Mechanism

(Stoichiometry imbalances may occur because of lumped parameter assumptions.)

Reaction	Model Values from Validation
hu + $NO_2 \rightarrow NO + O$	0.4 min^{-1}
$O\ (+\ O_2) + M \rightarrow O_3 + M$	1.32×10^{-5} $ppm^{-2}min^{-1}$
$O_3 + NO \rightarrow NO_2\ (+\ O_2)$	40 $ppm^{-1}min^{-1}$
$O + HC \rightarrow 2RO_2$	6100 $ppm^{-1}min^{-1}$
$OH + HC \rightarrow 2RO_2$	80 $ppm^{-1}min^{-1}$
$RO_2 + NO \rightarrow NO_2 + 0.5\ OH$	1500 $ppm^{-1}min^{-1}$
$RO_2 + NO_2 \rightarrow PAN$	6 $ppm^{-1}min^{-1}$
$OH + NO \rightarrow HNO_2$ (a)	10 $ppm^{-1}min^{-1}$
$OH + NO_2 \rightarrow HNO_3$ (a)	30 $ppm^{-1}min^{-1}$
$O_3 + HC \rightarrow RO_2$	0.0125 $ppm^{-1}min^{-1}$
$(H_2O + 2)\ NO + NO_2 \rightarrow 2HNO_2$ (b)	0.01 $ppm^{-1}min^{-1}$
hu + $HNO_2 \rightarrow NO + OH$	0.001 min^{-1}

(a) Rate constant lumps third body concentration.

(b) Water vapor lumped into rate coefficient.

completely independent from the photochemical reactions. Consequently, it is possible to employ several alternative photochemical reaction mechanisms, if so desired. The dispersion and chemical reactions are treated in an alternating step fashion. First, the pollutants are allowed to disperse through the grid system for a time interval, then the dispersion is frozen and a chemical reaction step occurs, etc. In the limit of very small time steps, this alternating procedure approaches the simultaneous operation of dispersion and chemical reactions.

The mathematical point method provides a very convenient means for merging a distribution of airborne and ground-based sources into a cell or grid type model which is essential for the treatment of photochemical reactions. However, because of the limitations of computer core storage and run time, the individual cells cannot be too small so that one tends to lose a certain amount of spatial and temporal resolution. This is the sacrifice which must be made if the photochemistry is to be treated without an intolerable consumption of computer time.

This model is not yet operational at Argonne but is expected to be so by approximately March, 1973, on the Chicago O'Hare data base. At the present time, there are no unusual difficulties expected with adapting emissions as calculated in this report to this model. The meteorological data appears to be the segment requiring the most adjusting to the proper format.

8.0 Conclusions and Observations

Future Significance of Airports as Air Pollution Sources

Based on an analysis of the proposed St. Louis Airport at Waterloo-Columbia, Illinois, it is expected that uncontrolled air pollution emissions from aircraft will approximately triple by the year 2000, despite the trend towards *higher* capacity aircraft and *lower* per passenger emissions. The forecasted aircraft activity levels and mix used for this computation is quite typical of future major commercial airports. These data indicate that airport complexes will become increasingly significant sources of air pollution, unless relatively effective emission controls are applied. This impact may be expected to become a major consideration in the development of environmentally sensitive land use and transportation system plans.

Trends in Airport Access Traffic

If access traffic at most major airports retains the general composition and mix characteristics associated with the proposed St. Louis facility, emissions from this source will decline as a result of the implementation of Federal Automotive Emission Standards. However, increases in population of vehicles will cause this trend to reverse by approximately 1985. If airports similar to the St. Louis facility are served by mass transit systems, then in the short term (3 to 5 years) the diversion of passengers from private automobiles to mass transit will result in significant emission reductions. By 1985, stricter emission controls for mass transit modes will be required in order to preserve this *relative* benefit. (Mass transit modes considered are diesel buses, diesel commuter trains, and electric rail transit—the latter increases power p[illegible] emissions).

Relative Importance of Aircraft vs Ground Vehicle Emissions

By 1975, the CO, HC, and NO_x emissions attributable to aircraft and ground vehicles (ground service vehicles and access traffic) will be of the same order of magnitude. By the year 2000, aircraft emissions will, in the absence of engine exhaust controls, be an order of magnitude higher than what is discharged by ground vehicles. This assumes that ground service vehicles and access traffic both comply with federal automotive emission standards. This indicates that there is likely to be a substantial increase in the need for aircraft emission controls.

Contributions from Airport Ground Service Vehicles

Ground service vehicles are a major contributor to airport emissions of carbon monoxide and hydrocarbons (approximately 12% for each pollutant). Their contribution could increase to approximately 24% of the total by 1990 if they remain uncontrolled (there are no proposed or anticipated controls for ground service vehicles at this time). This indicates that ground service vehicles offer an attractive opportunity for reducing airport-related emissions, particularly since they are generally fleet-operated and their control would not involve significant safety implications.

Contribution of Aircraft Taxi/Idle Modes

A large fraction (approximately 90%) of aircraft carbon monoxide and hydrocarbon emissions occurs during the taxi and idle modes. (This is based on the application of the latest Cornell emission factors to the activity at O'Hare International Airport and at the proposed St. Louis facility.) Operational controls, therefore, promise to be a relatively effective means of reducing airport-related emissions. It is necessary to note, however, that several additional factors, including noise abatement and safety implications, must be considered in the evaluation of aircraft ground operational strategies.

Secondary Airport-Related Emissions

Evaporative hydrocarbon emissions from fuel handling and storage are significant but are difficult to control because of the many small sources involved (i.e., the aircraft and ground vehicle fuel tanks). On the other hand, if vapor recovery systems or other such technique would prove economically and technically feasible, the control of this source would be appropriate.

Emissions from airport heating plants are relatively small but should be considered for control (particularly NO_x) as other airport sources are regulated.

Emissions derived from engine runup and testing at airports that are not considered major service centers (for example, O'Hare) also represent a relatively minor contribution to total airport emissions. At major service terminals such as the Los Angeles International Airport, runup and testing may be significant.

Relative Contributions of Airport and Surrounding Areas to Emissions of Air Pollutants

While airports are major sources of air pollution, they are generally no worse, on an emission density basis, than adjacent urbanized areas. The case study conducted at O'Hare indicated that carbon monoxide, hydrocarbons, nitrogen oxides, and particulate emission densities within the 10-square-mile O'Hare site. It must be noted, however, that the emission densities associated with the terminal and taxiways where most of the airport pollution is generated are considerably greater (possibly by a factor of 5 to 10) than what is characteristic of urban land. Care should therefore be taken in the use of emission-density-figures - particularly for new airports where the trend is toward very large land acquisitions.

An Increase in Residential Land Use in Airport Vicinities

Residential land development in the vicinity of O'Hare Airport (4 townships—115 square miles) has not been significantly discouraged by increased aircraft operations. Population increases since 1960 in the immediate vicinity of the airport have been as large or larger than in similar suburban areas. It would appear that once developers obtain appropriate zoning, or otherwise acquire the authority to construct residential dwellings, there is always a market and a buyer for the land.

Induced Development in the Airport Vicinity

The land use case study in the O'Hare Airport environs indicated that increased levels of activity predominate in the immediate vicinity of the site (1 to 3 miles). The largest growth has been in manufacturing and warehousing activities. Manufacturing activity in the 4-township study area surrounding O'Hare has increased approximately 38% since 1964, while the 6-county northeast Illinois average increased 22%. A definite indication of manufacturing and warehousing clustering in the immediate vicinity of the airport was observed. Residential land use, on the other hand, increased in density in proportion to the distance from the airport perimeter. Conventional planning practices have promoted the concentration of industrial and commercial activities in the immediate vicinity of the airport. Whatever the locational advantages of this arrangement may be, this type of land use plan tends to concentrate air pollution sources.

Directional Relation of Manufacturing Activity

Manufacturing land use in the O'Hare Airport study area indicated that there were extremely large increases on the side of the airport site that was away from the Chicago urban center. In the quadrant of the study area facing Chicago, manufacturing and warehousing increased approximately 37% from 1960 to 1970, while in the opposite quadrant, facing away from Chicago, manufacturing and warehousing activity increased approximately 250% during the same period. The absolute magnitudes of the growth on either side of the airport site were comparable.

The Relative Contribution of Land Use Activities to Airport Area Air Pollutant Emissions

Manufacturing and warehousing emissions in the O'Hare Airport area study are substantially greater (by approximately an order of magnitude) than emissions from residential, commercial or institutional sources; however, motor vehicle emissions in the study area are the dominant source of air pollutants in the airport vicinity - particularly, in the case of carbon monoxide, hydrocarbons, and nitrogen oxides. Even after a 90% emission reduction is realized as a result of applying the Federal Emission Standards, motor vehicles will remain the largest contributors of carbon monoxide and hydrocarbons. Uncontrolled manufacturing and warehousing emissions of nitrogen oxides, on the other hand, will then exceed those due to transportation sources by as much as a factor of 2 to 5.

The Adequacy of Airport Environmental Impact Statements

On the basis of a detailed review of two environmental impact statements for major airports (St. Louis and Dallas), we conclude that current airport impact statements fail to present an adequate appraisal of air pollution impacts. Often, little information is available to allow comparisons of predicted air quality with national standards within or external to an airport. Furthermore, virtually no information is available regarding the impact of induced development on the airport environs. It is recommended that airport-induced land development be established as a significant factor in airport environmental impact evaluation.

Air Pollution Potential for the Proposed St. Louis Airport

A meteorological and air pollution potential analysis for the proposed St. Louis airport in Waterloo-Columbia, Illinois, indicates that the southeast wind sector has displayed the highest frequency of stagnations, based on a two-year record of mixing height soundings at the St. Louis Gateway Arch. A southeast wind is favorable to the transport of air pollutants from the proposed airport site to the St. Louis metropolitan area. This wind category also has the third highest directional frequency. The distance from the airport to downtown St. Louis (approximately 19 miles) will, however, attenuate the effects of a southeast wind. It is important to note that the stationary and mobile source emission control regulations that are effective in the St. Louis urban area were designed to be *just* sufficiently stringent to achieve air quality standards. When St. Louis lies downwind of the pollutant plume emitted by the Waterloo-Columbia airport, particularly during stable atmospheric conditions that inhibit the lateral and vertical dispersion of the plume, air quality standards in St. Louis may be violated. This leads to the inference that there is a minimum distance between a major airport and an adjacent urban concentration, below which the airport may have an unacceptable impact on urban air quality. This distance is dependent on the magnitude of the airport and urban concentration as air pollution sources and the frequency with which the prevailing meteorological conditions enable the airport pollutant plume to pass over the urban area. Air quality models that are currently available can be employed to estimate this minimum distance.

APPENDIX A

A Description of the Aerial Photographic Technique for Determining Land Use

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APPENDIX A

For purposes of estimating emissions based on land utilizations in the vicinity of O'Hare airport, a historical land use analysis has been performed. Data for this analysis were obtained from a land use survey of approximately 125 square miles surrounding and including the airport. Aerial photographs (at the scale 1"=400') of these 125 square miles were obtained for four points in time during the 1960-70 decade (1970, 1966, 1964 and 1960)*. These photographs were first interpreted by identifying sites as belonging to one of nine rather gross activity classes as described in this Appendix. The nine basic activities were sampled in such a way that the most accurate data could be obtained at minimum cost. This sampling technique will also be discussed and illustrated in this Appendix. Finally, the raw data were tabulated and converted to acreage statistics at Argonne's computer facility.

Figure A.1 shows a map of the area employed in the historical land use survey. O'Hare Airport intersects the junction of four townships (Elk Grove, Maine, Addison and Leyden) which are located in Cook and DuPage Counties of Northeast Illinois. The boundaries of these four townships have been used to define the study area. Portions of Norwood Township and of the City of Chicago are also included within the study area.

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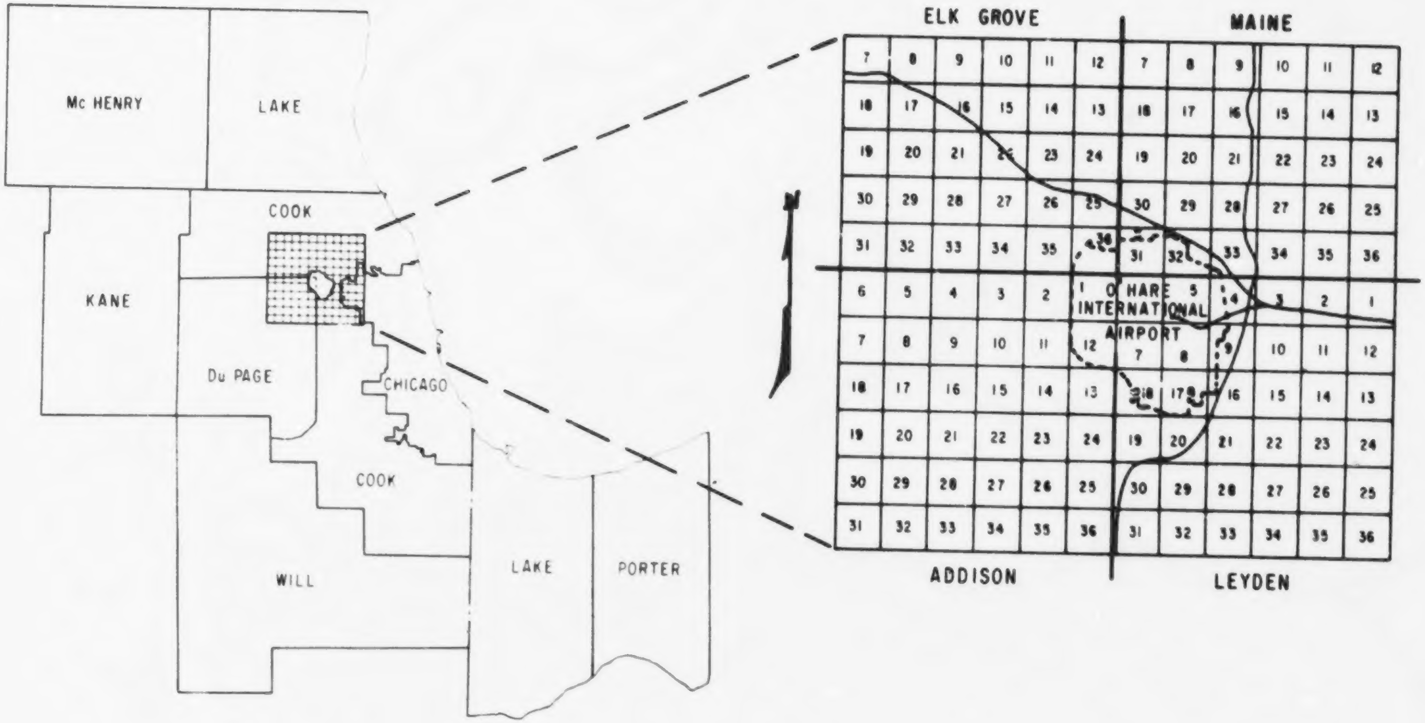
*These aerial photographs were obtained from two sources. The ones for 1970, 1966 and 1964 were borrowed from the Northeastern Illinois Planning Commission. Comparable photographs for the 1960 data were purchased from Chicago Aerial Survey.


Mc HENRY
LAKE
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Du PAGE
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WILL
LAKE
PORTER
ELK GROVE
MAINE
ADDISON
LEYDEN
O'HARE
INTERNATIONAL
AIRPORT

Fig. A.1 Four-Township Land Use Case Study Area Surrounding O'Hare Airport

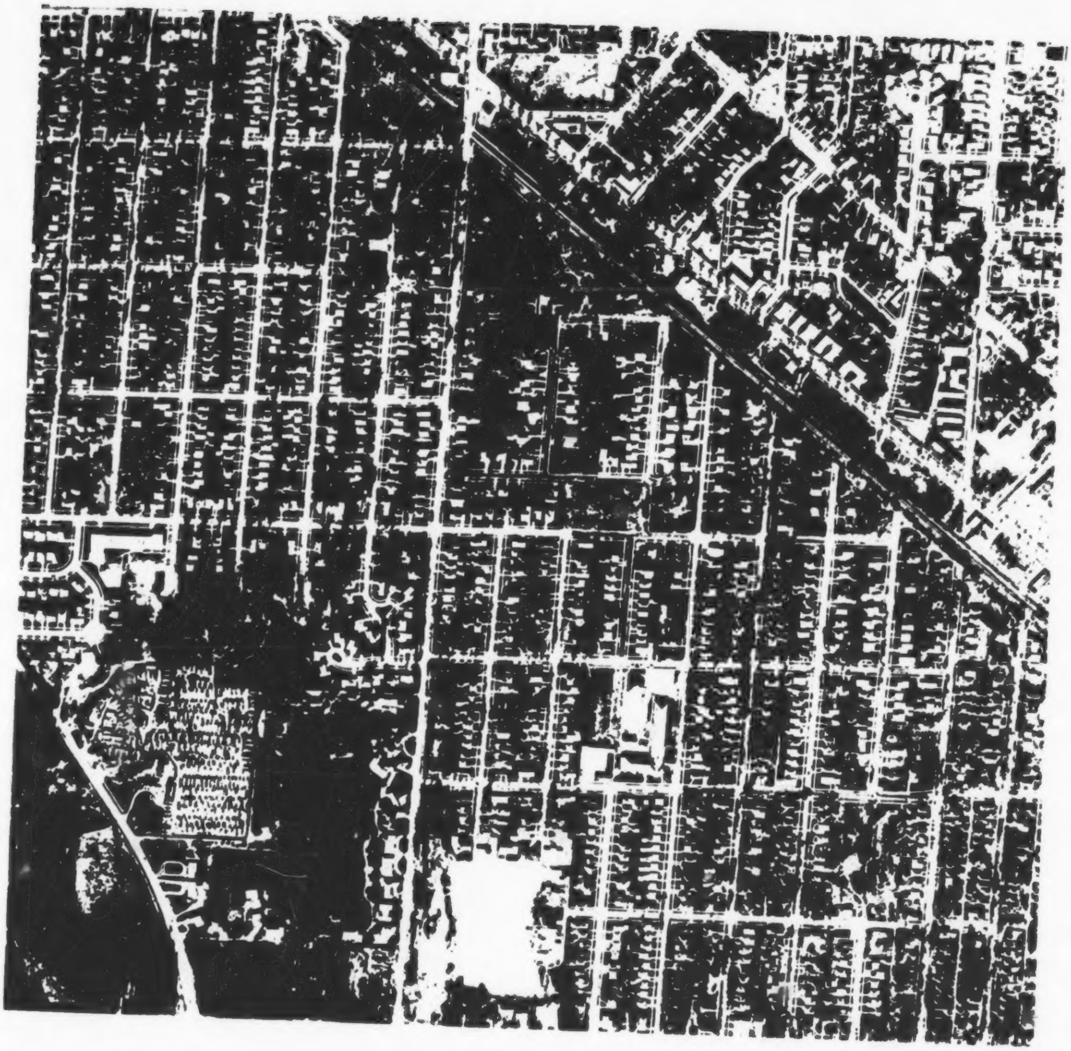
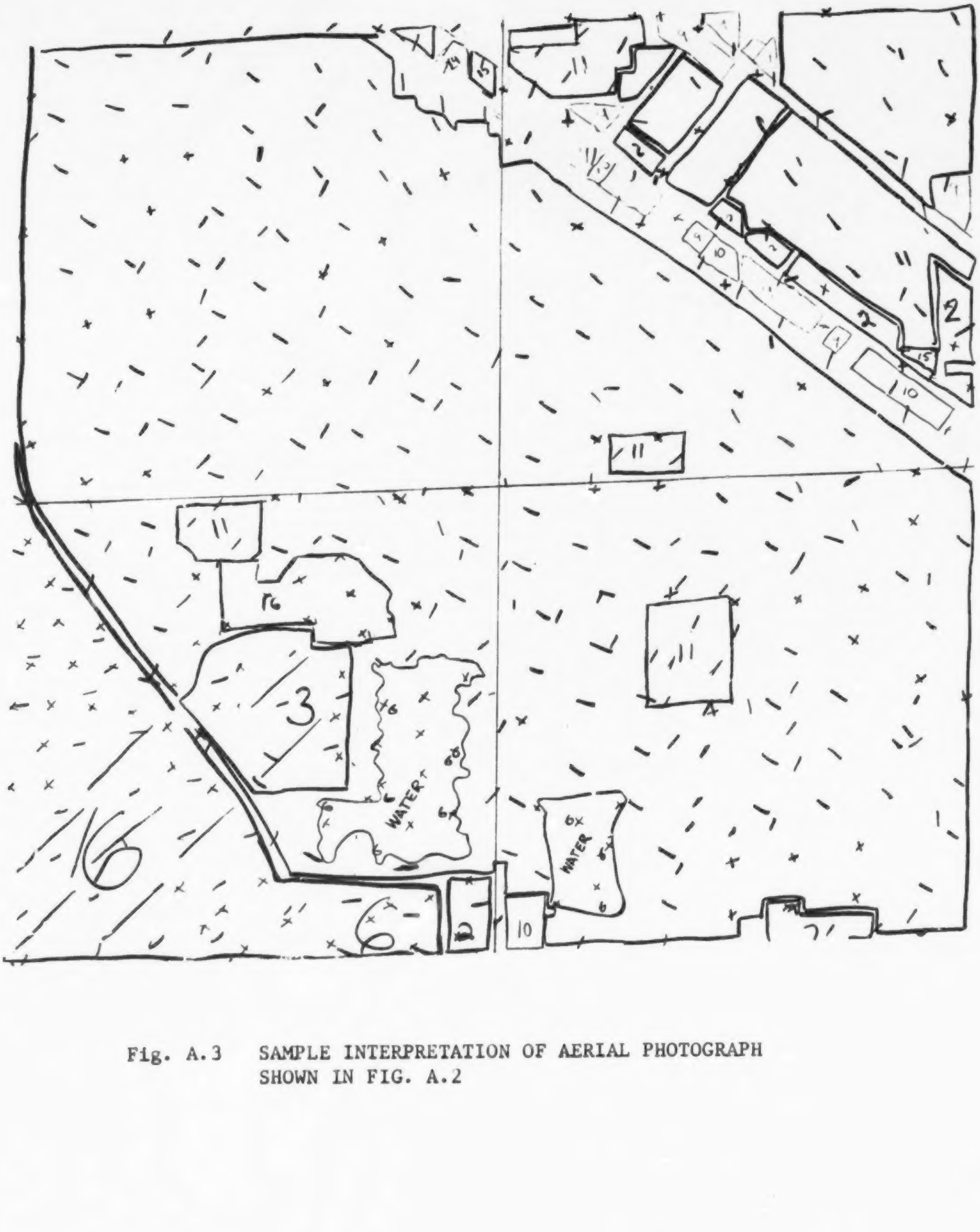


Fig. A.2 SAMPLE AERIAL PHOTOGRAPH FROM THE O'HARE STUDY AREA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16
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WATER
WATER
16
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7

Fig. A.3 SAMPLE INTERPRETATION OF AERIAL PHOTOGRAPH SHOWN IN FIG. A.2

Land Use Survey: Data Collection

As previously mentioned aerial photographs of the area were interpreted by identifying activities as belonging to one of nine activity classes. These land use classes are defined as follows:

Category 1: Residential - Single and Multifamily

Includes all land areas occupied by residential dwelling units. Structures comprised in this category are single family houses, town houses, garden apartments, four-plexes, low, medium-and high-rise developments. In the case of multiple-family dwellings adjacent parking facilities and land-scaped grounds are also included. For single-family residences located in rural areas, all land within 100 feet of each residence or estate is also classified as residential.

Category 2: Residential - Mobile Home Parks

These include all concentrations of three or more mobile home units situated apart from any adjacent sales or commercial display area. Isolated mobile home units are included within the other residential category.

Category 3: Commercial

Is representative of all display, sales, service and merchandising enterprises. The following activities are included in this class:

Wholesale Trade - facilities not adjacent or directly-related to the manufacture or processing of the product being marketed (excludes on-site warehouses.)

Retail Trade - all marketing outlets situated independently or in combination, the "predominant use" in shopping centers and central business districts.

Shopping Centers - Related parking facilities and landscaped areas.

Eating and Drinking places.

Nurseries and Orchards with directly-related marketing facilities.

Finance, Insurance and Real Estate services and supporting office facilities.

Business services and related office facilities (advertising, credit-adjustment collection, mailing, steno and employment, building maintenance, reproduction and news).

Research and Development services.

Personal services (laundering, dry cleaning, tailoring, photographic, beauty/barber, funeral, shoe and apparel, vehicle rental services).

Professional services (medical, health (non-hospital) office and lab services; private rest homes, legal engineering, architectural, accounting, auditing and urban planning (6594) services).

Repair services (vehicle, electrical appliance, jewelry, furniture repair, alterations and maintenance services).

Contract construction and skilled trade service (building, and building systems and finishing services).

Welfare and charitable services (non-religious).

Business, professional, labor union and fraternal associations and organizations office and meeting facilities.

Animal husbandry services (veterinarian, animal hospitals, hatcheries).

Hotels, motels, tourist courts and transient lodgings.

Entertainment - indoor and outdoor: amphitheaters, motion pictures, legitimate and playhouse theaters, dancing pavilions.

Sports - stadia, arenas and field houses, racetracks, etc.

Indoor tennis courts, bowling centers, ice-and roller skating facilities.

Parking garages, ancillary structures, and landscaped property included.

Category 4: Industrial (Except Warehousing)

These activities also include all related offices, parking and loading areas, storage yards, and surrounding landscaped grounds located within that parcel.

Manufacturing activities - All heavy, light and general manufacturing activities.

Processing activities - industrial, agricultural, natural resources products.

Category 5: Warehousing

Includes all warehousing and storage structures not directly adjacent to a related primary activity of a manufacturing activity.

Category 6: Institutional

Is representative of all of the following institutional services:

Government Services

Executive, legislative, judicial facilities.

Protective (police, firefighting, civil defense) service facilities.

Penal institutions - prisons, detention homes, juvenile homes, etc., including all confinement homes.

Hospital Services (public and private) and medical and mental health and rehabilitation facilities, sanitoria, rest homes and convalescent centers.

Educational Services: (including adjacent recreational facilities and grounds serving the school)

Nursery, primary, secondary education.

University, college, junior college, graduate-professional academies.

Special training and education (vocational, business, skills, arts, etc.)

Religious Services:

Churches, synagogues, temples
Convents, seminaries (non-secular)

Military Bases and Installations:

Military training bases and armorys facilities (including barracks, exchange, and recreation activities).

Military defense installations.

Military storage depots, transportation centers, maintenance facilities.

Military administration, command and communication centers.

Military air fields and dock facilities.

Public Buildings

Cultural centers: Libraries, museums, art galleries (non-commercial), planetaria, acquariums.

Public assembly, public auditoriums, convention and exhibition halls.

Category 7: Transportation, Communications and Utilities (T.C.U.)

Transportation Facilities

Railroad terminals (passenger and freight), equipment and maintenance facilities.

Rapid rail equipment and maintenance facilities.

Bus and taxi terminals (passenger), equipment and maintenance facilities and garages.

Motor freight (trucking) terminals, vehicle storage yeards, equipment and maintenance facilities.

Marine craft and freight terminals, equipment and maintenance facilities.

Communications Facilities

Telephone exchange stations, relay towers, switching and computerized operations centers.

Radio broadcasting and transmitting facilities.

Television broadcasting and transmitting facilities.

Utilities Functions

Electrical transmission rights-of-way general plants, regulation and switching sub-stations.

Petroleum and Natural Gas pipeline rights-of-way, plants, storage and distribution facilities.

Water pipeline rights-of-way, treatment plants, storage and distribution facilities.

Sewage treatment plants, sludge drying beds, disposal and control stations.

Solid waste disposal (refuse) incinerators, garbage grinding and compositing plants.

Sanitary landfill areas, industrial disposal sites, slag dumps, etc.

Railroad Rights-of-Way and Yard Facilities

Railroad rights-of-way, including switching and marshalling yards.

Rapid transit rights-of-way, including switching and storage yards, when separated from a public thoroughfare.

Airports

Airport, heliport and flying field runway and taxiing facilities, terminal (passenger and freight), storage areas and all adjacent property owned by the airport authority or flying field.

Highway and Street Right-of-Way

All public freeways, expressways, parkways, arterials, collector and distributor streets (not included within Private developments).

Freeways', expressways', parkways' and limited access arterials' right-of-way - measured between outside service drive curbing or fencing.

Surface thoroughfare right-of-way - measured from sidewalk to sidewalk where applicable.

Mines and Quarries

Includes all areas previously or currently committed to excavation activity.

Adjacent property deeded to that same company or individual, and held for future mining operations should be included within the vacant - under development/committed category (8).

Category 8: Vacant, Agricultural

Vacant, Agricultural and Forest Areas

Agricultural activity areas: crops, livestock, fowl, housing-raising farms; orchards, pasture lands, horticultural specialization.

Undeveloped and unused land area.

Forecasted areas (reserve or non-reserve) within Non-Urban surroundings.

Vacant, Committed/Under Development

Includes areas or parcels (1) under ownership by a corporation, organizations, institutions or non-agriculturally involved individual with a currently-developed activity directly adjacent or included thereupon; (2) where construction or excavation activity is currently in process.

Category 9: Recreation - Open Space - Water

Public and Quasi-Public Recreation/Open Space Area

Recreational activities - golf courses, tennis courts, skating areas, riding stables, skiing, tobogganing areas, golf driving ranges, miniature golf and go-cart tracks.

Playgrounds, athletic and swimming areas (indoor and outdoor).

Marinas - boat laundering, rental and docking facilities, yacht clubs.

Camping and picnicing areas, also organized group camp areas.

Resort areas and facilities.

General park and recreation areas, including leisure ornamental parks.

Botanical gardens and arboretums.

Zoological parks.

Fairgrounds and amusement parks.

Historic and monument sites.

Cemeteries

Includes all burial ground, memorial parks/gardens, mausoleums and interment activities.

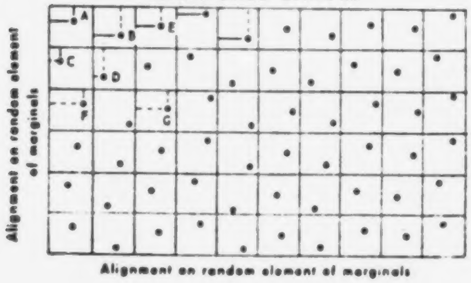
Water

Includes all rivers, streams or creeks exceeding 1/8 inch on a 1":400 aerial photo. All lakes and ponds are also included in this class.

All of the land use sites in each aerial photograph were allocated to one of these nine categories by placing a transparent overlay on the photo. The various sites were then outlined on this overlay with different colored pencils.* An example of one of these aerial photographs is shown in Fig. 2. The interpreted overlay for this photograph is illustrated in Fig. 3. Quantities of land defined by the nine categories were then determined, using a sampling method described by Berry and Baker.[47] According to this method, dots are assigned to cells of a grid which is reproduced on a second transparent overlay. After removing the first overlay from the interpreted aerial photograph, it is laid over the dot grid and the dots falling in each land use category are counted and recorded on a coding sheet.

This dot procedure is referred to as a "stratified systematic sample." Berry and Baker describe and illustrate its construction as follows:

> First, point A is selected at random. The x coordinate of A is then used with a new random y coordinate to locate B, a second random y coordinate to locate E, and so on across the top row of strata. By a similar process, the y coordinate of A is used in combination with random x coordinates to locate point C and all successive points in the first column of strata. The random x coordinate of C and y coordinate of B are then used to locate D, of E,


A STRATIFIED SYSTEMATIC UNALIGNED SAMPLE

A
B
E
C
D
F
G
Alignment on random element of marginals
Alignment on random element of marginals

---

*The persons employed for this task were inexperienced in aerial photo interpretation. Mr. Walter Vissotski of the Northeastern Illinois Planning Commission (NIPC) was consulted to conduct a three-day course to the interpreters and one supervisor. Where site interpretation was difficult or ambiguous, Mr. Vissotski advised consulting similar overlays created by NIPC in generating the 1970 land use inventory for the six-county region. These overlays were loaned to the Argonne Center for Environmental Studies, along with the aerial photos mentioned above.

> and F to locate G, and so on until all strata have sample elements. The resulting sample combines the advantages of randomization and stratification with the useful aspects of systematic samples, while avoiding possibilities of bias because of the presence of periodicities, (Berry and Baker, 1968, p. 93).

The sample used in this study was generated by the Northeastern Illinois Planning Commission in conjunction with that agency's 1970 land use survey. This sample contained 540 dots per square mile (i.e. normal 640 acre section) and was created in the following manner. First a grid consisting of 576 cells was drawn and one dot was plotted in each cell according to the above method. Next, boundary lines were drawn around the space which would encompass the normal square mile area and 36 of the plotted points fell outside these boundaries. These extra sampling points were left on the dot grid to handle sections which appeared slightly larger than one square mile, due to displacement inherent in aerial photography (Branch, 1971 pp. 149-153).[48] Next, quarter-section boundaries were drawn on the square mile dot grid. And finally, half of the lines defining the cells used in plotting the dots were eliminated to reduce the coder's eye tension. This procedure left four dots in each of 144 cells. The resulting dot grid is illustrated in Fig. A.4.

Amounts of land utilized by each class of land use activity were then determined by counting the dots falling in the particular sites on the interpreted sectional photographs. This was done by placing the clear plastic overlays with the sites outlined and numbered in different colored pencils over the dot sample.* The number of dots falling into each of the nine land use categories were then recorded by quarter-section subtotal on a coding sheet. This coding sheet is illustrated in Fig. A.5. A different sheet

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*The interpreted plastic overlays were systematically aligned with the dot sample using a common boundary and one point. The western boundary of the interpreted plastic overlay was always lined up with the western boundary of the dot grid. Next, the northwest corner of the overlay was matched with its corresponding point on the dot grid.

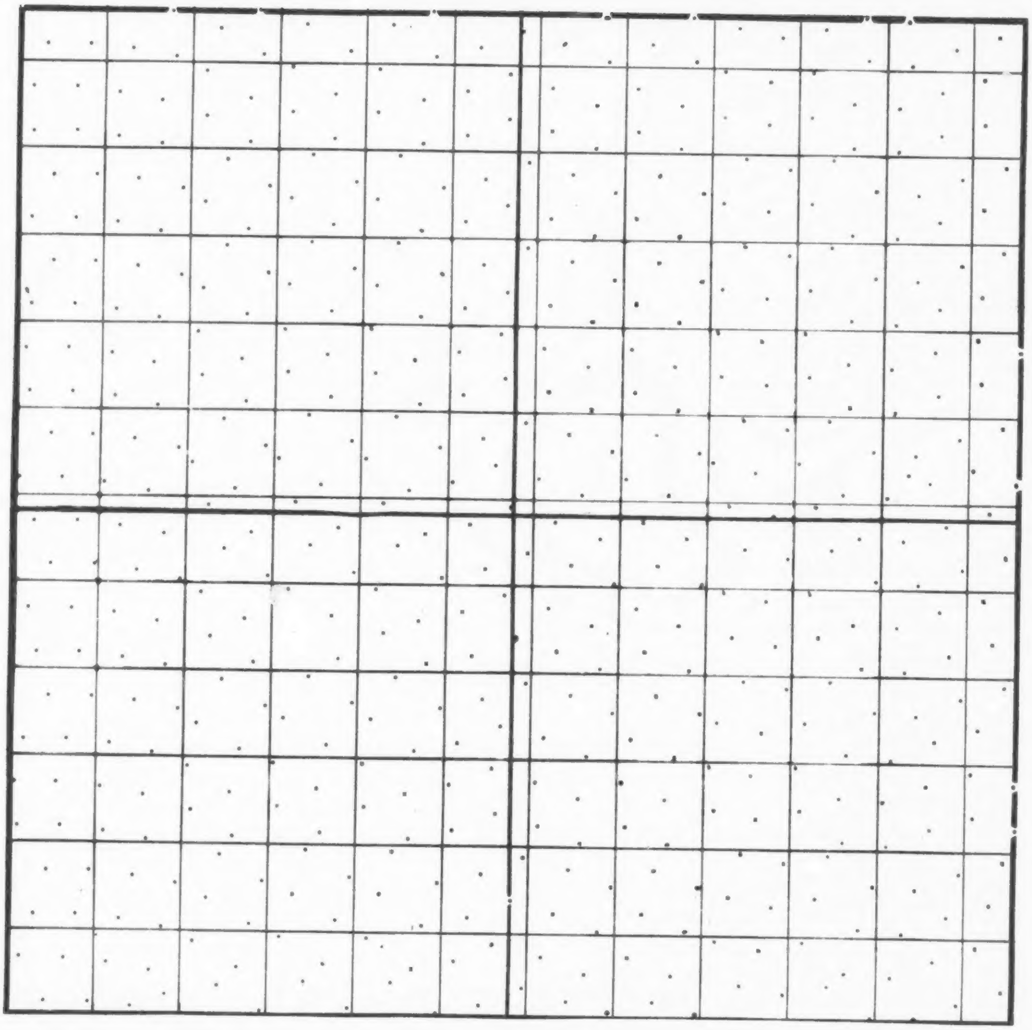
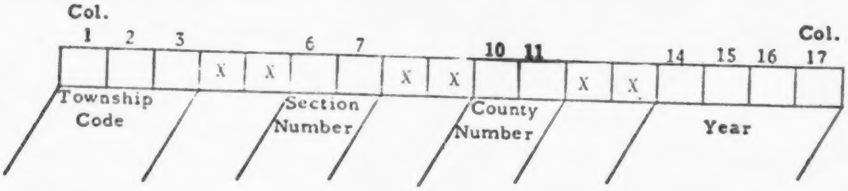


Fig. A.4 Sample Dot Grid

Fig. A.5 Sample Land Use Code Sheet

Argonne National Laboratory
Center for Environmental Studies
Historical Survey - Airport Land-Use (1972)
O'Hare Airport

Township ______
County ______
Section ______
Year ______
Date Coded ______
Coder ______


Col.
1
2
3
X
X
6
7
X
X
10
11
X
X
14
15
16
Col.
17
Township Code
Section Number
County Number
Year

LAND USE CATEGORIES		QUARTER-SECTION 1 NE	2 NW	3 SW	4 SE	Total	Col.
RESIDENTIAL-Single and Multi Family	1						30
RESIDENTIAL-Mobile Home Parks	2						35
COMMERCIAL	3						40
INDUSTRIAL (Except Warehousing)	4						45
WAREHOUSING	5						50
INSTITUTIONAL	6						55
T.C.U. (Rights of Way)	7						60
VACANT, AGRICULTURAL	8						65
RECREATION-Open Space-Water	9						70
TOTAL							

was created for each of the four years for all sections in the study. Computer cards used to analyze these data were then key punched directly from the coding sheets. The numbers at the top and in the right-most column of the sheet refer to columns in which data were left-justified in the punched card format.

The total number of acres entered on each coding sheet was obtained from the U.S. Geologic Survey.* This total acreage was used to calibrate the dot-per-acre ratio with the topographical displacement which varied from photograph to photograph. In this dot-per-acre (DAR) calibration, the acreage in any given section (i) was divided by the total number of dots falling in that section.

$$DAR_i = \frac{A_i}{\sum D_i} \qquad (A.1)$$

This ratio was then used to compute the acreage consumed by the various land use categories in that section for each of the four years.

$$A_{LU_{ki}} = DAR_i \sum D_{LU_{ki}} \qquad (A.2)$$

where:

$A_{LU_{ki}}$ = Acreage consumed by land use category k in section i.

DAR_i = Dot-per-acre ratio calibrated for a specific photograph for section i.

$D_{LU_{ki}}$ = Number of dots falling in sites of land use category k in section i.

---

*These results assume perfectly accurate interpretation of the aerial photographs.

Statistical Accuracy of the Stratified Systematic Unaligned Sample

The statistical error inherent in the 540-dot sample has been calculated by the Northeastern Illinois Planning Commission.[49] Their analysis showed that the sample yielded results which were no more than ± 10 percent in error 95.75 percent of the time, and no more than ± 20 percent in error 99.9 percent of the time. This analysis demonstrated that, whereas a larger number of sample points would provide greater statistical accuracy, the number of sample points would have to be greatly increased before even a slight reduction of error could be realized. Therefore, the 540-dot sample was selected because it optimized the statistical accuracy of the data with respect to the time and effort required to collect it. An additional analysis of the reproducability of results was performed for this study.

For this test of reproducability, land use acreages derived from the 540-dot sample were correlated with planimeter measurements which provide a nonsampled measure of land use acreages for any given section. Four photographs (each containing approximately 640 acres) were selected for this comparative analysis.[*] In terms of complexity, these photos were medium to difficult to interpret, and they contained 28 of a possible 36 land usages.

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[*] One photograph was selected from each of the four townships, and these were varied among the years over which land use change was being surveyed in this study. The photographs selected for this correlation of reproducability were:

Addison Township	Section 22	1960
Elk Grove Township	Section 25	1964
Leyden Township	Section 21	1966
Maine Township	Section 32	1960

The two measures of acreage consumed by the 28 section-specific land use categories were taken from the transparent overlays used to interpret the four photographs. First, the number of dots falling in the various land use categories were counted and converted into acreage figures as described above. Second, nonsampled measures of the land use consumption were taken. The colored lines defining land use sites on the interpreted plastic overlays were traced with the stilus of a planimeter, and the readings indicated on the instrument were tabulated and converted into acreage data. Next, the acreage obtained from the dot sample were regressed on acreages computed from the planimeter readings using a linear least squares model.

The slope of this model is b and the intercept is a.

$$b = \frac{N\sum xy - \sum x \ \sum y}{N\sum x^2 - \sum x^{\,2}} \qquad \text{(A.3)}$$

where:

b = slope of the straight least-square line describing the association between x and y. (Or: the ratio of the co-variation in x and y to the sum of squares.)

x = land use acreage as measured by the planimeter readings.

y = land use acreage as measured by 540-dot stratified unaligned sample.

and where:

$$a = \frac{\sum y - b\sum x}{N} \qquad \text{(A.4)}$$

The resulting a and b coefficients were then used to compute new scores for each y predicted from the association of the two independent measures of land usage for all of 28 land use categories in the four-section test. These predicted (y_p) acreages were computed using the relation:

$$y_p = a + bx \qquad \text{(A.5)}$$

The principles of the linear least squares regression model and the computation of predicted values for y are illustrated in Fig. A.6.

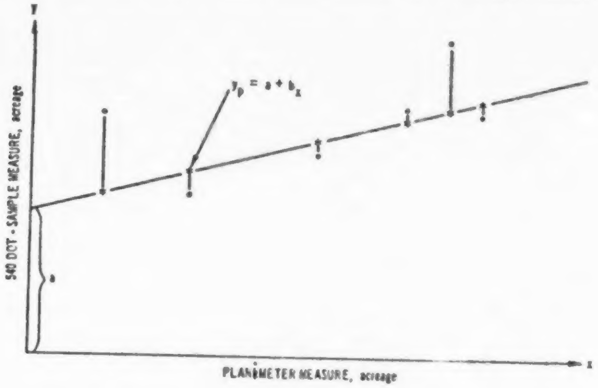

Fig. A.6 Linear Regression Model

Finally, for each data point the predicted y value was subtracted from its actual value and the difference taken as a proportion of the actual y value.

$$y_e = \frac{y_p}{y} \qquad \text{(A.6)}$$

This procedure yielded standardized error scores for land use acreage computed from the 540-dot sample compared with the same acreages computed from planimeter measures. The resulting values are interpreted as the proportion of the dot-sample acreage for a section-specific land use category which is unexplained by the association between the dot-sample and planimeter measures over all of the 28 data points.

The results of these tabulations are illustrated in Table A.1. Columns 1-4 define the section-specific land use categories for which the relative errors have been calculated in this test. Columns 9 and 10 indicate the value and rank of this error. This table demonstrates that the error ranges from 50.93 percent to .23 percent. More importantly, an error greater than 10 percent is obtained in only 8 of the 28 land use categories examined.

Table A.1 The Association between Measures of Land Use Averages: 540 Dot Sample vs Planemeter Measurement for 28 Land Use Categories from Four Sections

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
				X	Y	$Y-Y_p$		$\frac{Y-Y_p}{Y}$	
Township	Section	Year	Land Use Category	Planemeter	Dot	Score	Rank	Score	Rank
MA	32	60	4	4.0	3.2	-1.63	20	.5093	1
AD	22	66	6	5.5	4.7	-1.63	21	.3468	2
EG	25	64	5	10.9	9.5	-2.71	23	.2326	3
EG	25	64	6	2.1	2.4	- .54	17	.2250	4
AD	22	66	4	15.5	21.0	4.71	4	.2243	5
LY	21	66	5	18.0	23.8	5.02	3	.2109	6
EG	25	64	1	4.7	4.8	- .73	19	.1521	7
EG	25	64	9	42.8	48.7	5.21	2	.1069	8
LY	21	66	3	36.4	34.5	-2.61	24	.0757	9
LY	21	66	6	30.8	33.3	1.77	7	.0531	10
LY	21	[illegible]	4	57.6	60.7	2.47	5	.0407	11
MA	32	60	8	110.6	106.5	-4.53	26	.0421	12
LY	21	66	9	16.5	16.7	- .59	18	.0353	13
LY	21	66	8	57.2	55.9	-1.93	22	.0345	14
MA	32	60	3	21.0	22.4	.63	10	.0281	15
MA	32	60	1	78.3	80.9	2.05	6	.0253	16
EG	25	64	7	126.0	123.6	-2.77	25	.0224	17
LY	21	66	1	385.8	377.2	-7.98	28	.0212	18
AD	22	66	1	35.9	37.4	.79	9	.0211	19
EG	25	64	8	295.0	288.9	-5.83	27	.0202	20
AD	22	66	5	1.5	2.3	- .04	15	.0174	21
EG	25	64	3	33.2	34.5	- .58	11	.0168	22
AD	22	66	8	561.7	568.7	8.29	1	.0145	23
LY	21	66	7	39.1	39.3	- .50	16	.0127	24
EG	25	64	4	58.2	59.4	.57	12	.0096	25
MA	32	64	2	66.7	67.8	.50	13	.0074	26
MA	32	60	2	5.6	6.4	- .03	14	.0047	27
MA	32	60	7	420.4	420.6	.95	8	.0023	28

As expected, the larger errors are found in the categories consuming relatively few acres. Each of the 6 categories with an error greater than 20 percent consume less than 25 acres using either of the two measures, and the 10 categories with an error greater than 5 percent consume less than 50 acres. Most significantly, all 6 categories consuming more than 100 acres have less than a 5 percent error; and only one of these errors is greater than 2.24 percent.

We conclude from the results of this test that the 540-dot sample and the planimeter measure yield very similar land use acreages. This is verified in an aggregate fashion using the product moment correlation (r) which measures the extent to which data points are scattered (i.e., dispersed) about the regression line describing the association between the two land use measures. This r coefficient is .9997 where r is computed using the formula:

$$r = \frac{N\sum xy - \sum x \quad \sum y}{\sqrt{N\sum x^2 - \quad \sum x^{\,2} \quad N\sum y^2 - \quad \sum y^2}} \qquad (A.7)$$

APPENDIX B

Detailed Land Use Data (Acreages) for Addison, Elk Grove, Leyden and Maine Townships for the four study years; 1960, 1964, 1966 and 1970

RESIDENTIAL (Single-Multiple) — LEYDEN TOWNSHIP

SECTION	1960	1964	1966	1970
1	341.1	347.2	343.5	337.4
2	299.5	289.5	316.0	368.4
3	7.2	3.5	15.1	14.9
4	51.3	73.5	95.1	105.9
5	0.0	0.0	0.0	0.0
6	0.0	0.0	0.0	0.0
7	0.0	0.0	0.0	0.0
8	0.0	0.0	0.0	0.0
9	23.9	16.7	33.8	33.5
10	0.0	1.2	5.9	6.9
11	258.2	288.1	334.8	376.4
12	421.0	412.9	421.9	448.7
13	265.4	311.0	251.3	263.1
14	191.7	171.9	183.2	203.6
15	126.0	111.4	148.3	123.9
16	134.3	144.3	156.3	157.2
17	1.1	1.2	0.0	0.0
18	0.0	4.7	0.0	1.2
19	3.4	2.4	4.8	4.8
20	2.2	3.6	2.4	0.0
21	250.6	306.3	303.4	321.3
22	60.5	57.2	52.7	69.8
23	172.7	199.5	200.0	197.4
24	332.8	345.6	374.4	364.9
25	409.9	390.9	423.8	389.0
26	150.0	158.3	185.1	240.4
27	211.0	209.7	205.4	228.5
28	355.3	371.0	379.5	394.4
29	416.1	419.3	419.6	442.7
30	109.0	121.6	149.6	140.4
31	84.4	72.6	91.4	86.8
32	434.0	413.5	400.8	430.7
33	236.0	235.1	259.4	257.7
34	62.2	53.0	65.2	72.0
35	30.5	30.9	28.4	31.9
36	389.7	369.8	339.0	402.5

RESIDENTIAL (Single-Multiple) — MAINE TOWNSHIP

SECTION	1960	1964	1966	1970
7	301.1	248.4	263.7	270.8
8	19.1	20.8	21.0	26.4
9	27.7	41.7	37.7	63.7
10	71.2	122.2	142.8	178.2
11	217.2	269.6	272.9	290.4
12	326.2	314.4	323.2	294.6
13	336.9	375.8	436.1	417.7
14	173.3	201.4	238.3	293.9
15	147.1	210.2	313.8	416.1
16	83.0	94.3	102.8	125.3
17	211.8	205.0	212.5	193.0
18	191.0	218.8	211.9	192.3
19	211.3	200.7	207.1	196.0
20	395.8	356.2	376.2	345.7
21	148.8	148.1	165.1	172.5
22	295.3	326.6	341.9	380.8
23	185.2	169.0	204.4	234.0
24	362.4	403.4	397.1	418.9
25	445.2	425.2	462.0	414.3
26	314.1	293.8	314.9	351.5
27	333.5	337.0	372.4	354.6
28	184.8	180.4	186.2	172.3
29	239.7	275.2	296.7	310.6
30	48.9	58.9	48.7	70.8
31	1.2	0.0	0.0	0.0
32	50.2	30.8	28.1	45.4
33	283.3	253.5	285.6	293.9
34	147.2	158.4	134.6	197.1
35	458.2	424.7	386.1	400.0
36	399.8	405.0	381.7	405.1

RESIDENTIAL (Single-Multiple) ADDISON TOWNSHIP

SECTION	1960	1964	1966	1970
1	0.0	0.0	0.0	0.0
2	25.5	47.8	36.2	21.7
3	51.6	67.3	79.4	73.6
4	32.3	39.8	34.4	25.5
5	56.0	62.3	75.3	55.8
6	27.9	29.9	35.7	19.2
7	51.3	61.7	68.1	71.2
8	238.1	237.5	274.8	248.9
9	62.2	87.8	66.2	74.8
10	268.9	291.4	320.6	282.8
11	41.5	45.1	46.7	37.8
12	2.4	0.0	0.0	0.0
13	115.6	133.6	149.8	142.4
14	232.2	253.4	271.3	228.6
15	149.1	152.4	270.9	252.5
16	68.9	145.3	155.8	196.7
17	24.4	45.8	79.7	94.5
18	38.9	65.7	56.4	62.4
19	29.6	25.2	37.6	109.2
20	118.8	137.6	174.3	205.0
21	60.7	101.1	119.0	123.8
22	117.2	118.4	167.3	151.5
23	228.2	236.3	246.0	203.8
24	191.9	172.4	219.4	203.6
25	102.9	121.3	161.8	161.2
26	58.0	60.4	71.5	53.5
27	169.6	187.2	202.4	146.5
28	221.1	242.0	236.3	237.5
29	83.3	127.0	139.4	200.5
30	40.2	78.2	87.7	86.4
31	23.8	22.9	24.8	10.6
32	56.7	67.3	58.6	37.8
33	181.3	140.6	179.8	127.5
34	205.9	258.3	271.6	237.0
35	292.3	292.1	296.7	262.8
36	192.5	189.7	215.3	179.2

RESIDENTIAL (Single-Multiple) ELK GROVE TOWNSHIP

SECTION	1960	1964	1966	1970
4	3.5	5.0	5.9	7.1
5	0.0	7.3	9.4	7.9
6	1.1	5.0	18.9	15.1
7	1.8	9.3	24.6	24.4
8	25.0	48.8	81.4	169.9
9	51.0	111.4	164.6	290.0
10	186.6	235.2	282.8	367.2
11	301.9	344.2	326.7	345.4
12	330.1	336.6	344.8	373.0
13	170.3	372.0	372.0	394.3
14	137.5	223.4	240.0	290.3
15	37.0	56.6	137.4	252.9
16	44.1	53.0	61.4	54.7
17	2.3	1.2	1.2	0.0
18	3.4	0.0	1.2	0.0
19	5.4	2.2	4.7	0.0
20	6.8	6.9	4.5	8.8
21	65.1	67.6	37.9	62.6
22	23.5	41.2	31.6	77.3
23	32.9	39.6	21.4	27.1
24	150.1	264.1	299.3	423.5
25	3.6	4.8	4.7	6.0
26	44.0	35.8	46.5	38.7
27	13.9	53.9	53.9	46.0
28	246.1	281.0	266.5	305.0
29	11.3	33.2	24.3	81.6
30	2.3	0.0	1.2	1.2
31	21.2	29.6	42.6	50.3
32	5.9	43.8	126.1	279.4
33	214.5	313.9	327.7	307.5
34	16.8	20.8	16.8	17.8
35	12.8	8.8	1.2	0.0
36	32.4	35.4	37.6	21.8

RESIDENTIAL (Mobile Home Parks) — LEYDEN TOWNSHIP

SECTION	1960	1964	1966	1970
1	0.0	0.0	0.0	0.0
2	0.0	0.0	0.0	0.0
3	0.0	0.0	0.0	0.0
4	0.0	0.0	0.0	0.0
5	0.0	0.0	0.0	0.0
6	0.0	0.0	0.0	0.0
7	0.0	0.0	0.0	0.0
8	0.0	0.0	0.0	0.0
9	0.0	0.0	0.0	0.0
10	8.0	13.2	10.6	13.8
11	0.0	0.0	0.0	0.0
12	0.0	0.0	0.0	0.0
13	0.0	0.0	0.0	0.0
14	0.0	0.0	0.0	0.0
15	0.0	0.0	0.0	0.0
16	1.3	1.2	2.4	0.0
17	0.0	0.0	0.0	0.0
18	0.0	0.0	0.0	0.0
19	0.0	0.0	0.0	0.0
20	0.0	0.0	0.0	0.0
21	0.0	0.0	0.0	0.0
22	4.7	4.8	0.0	0.0
23	0.0	0.0	0.0	0.0
24	0.0	0.0	0.0	0.0
25	0.0	0.0	0.0	0.0
26	0.0	0.0	0.0	0.0
27	0.0	0.0	0.0	0.0
28	0.0	0.0	0.0	0.0
29	0.0	0.0	0.0	0.0
30	0.0	0.0	0.0	0.0
31	0.0	0.0	0.0	0.0
32	0.0	0.0	0.0	0.0
33	0.0	0.0	0.0	0.0
34	0.0	0.0	0.0	0.0
35	15.3	17.8	22.5	3.5
36	0.0	0.0	0.0	0.0

RESIDENTIAL (Mobile Home Parks) — MAINE TOWNSHIP

SECTION	1960	1964	1966	1970
7	0.0	0.0	0.0	0.0
8	0.0	0.0	0.0	0.0
9	0.0	0.0	0.0	0.0
10	0.0	0.0	0.0	0.0
11	0.0	0.0	0.0	0.0
12	0.0	0.0	0.0	0.0
13	0.0	0.0	0.0	0.0
14	7.2	9.6	9.3	0.0
15	0.0	0.0	0.0	0.0
16	0.0	0.0	0.0	0.0
17	11.1	13.1	11.4	15.2
18	0.0	0.0	0.0	0.0
19	0.0	0.0	0.0	0.0
20	0.0	0.0	0.0	0.0
21	0.0	0.0	0.0	0.0
22	0.0	0.0	0.0	0.0
23	0.0	0.0	0.0	0.0
24	0.0	0.0	0.0	0.0
25	0.0	0.0	0.0	0.0
26	0.0	0.0	0.0	0.0
27	15.2	15.4	17.8	15.5
28	0.0	0.0	0.0	0.0
29	17.8	20.1	16.4	19.0
30	0.0	0.0	0.0	0.0
31	0.0	0.0	0.0	0.0
32	6.4	7.1	7.0	6.3
33	16.8	14.8	15.7	14.9
34	0.0	0.0	0.0	0.0
35	0.0	0.0	0.0	0.0
36	0.0	0.0	0.0	0.0

RESIDENTIAL
(Mobile Home Parks)

ADDISON TOWNSHIP

SECTION	1960	1964	1966	1970
1	0.0	0.0	0.0	0.0
2	0.0	0.0	0.0	0.2
3	0.0	0.0	0.0	0.0
4	0.0	0.0	0.0	0.0
5	0.0	0.0	0.0	0.0
6	0.0	0.0	0.0	0.0
7	0.0	0.0	0.0	0.0
8	0.0	0.0	0.0	0.0
9	0.0	0.0	0.0	0.0
10	0.0	0.0	0.0	0.0
11	0.0	0.0	0.0	0.0
12	0.0	0.0	0.0	0.0
13	0.0	0.0	0.0	0.0
14	0.0	0.0	0.0	1.9
15	0.0	9.4	0.0	0.0
16	7.0	9.4	9.6	8.5
17	0.0	0.0	0.0	0.0
18	0.0	0.0	0.0	0.0
19	0.0	0.0	0.0	0.0
20	0.0	0.0	0.0	0.0
21	0.0	0.0	0.0	0.0
22	0.0	0.0	0.0	0.0
23	0.0	0.0	0.0	0.0
24	0.0	0.0	0.0	0.0
25	0.0	0.0	0.0	0.0
26	0.0	0.0	0.0	0.0
27	0.0	0.0	0.0	0.0
28	0.0	0.0	0.0	0.0
29	0.0	0.0	0.0	0.0
30	0.0	0.0	0.0	0.0
31	0.0	0.0	0.0	0.0
32	0.0	0.0	0.0	0.0
33	0.0	0.0	0.0	0.0
34	0.0	0.0	0.0	0.0
35	0.0	0.0	0.0	0.0
36	0.0	0.0	0.0	0.0

RESIDENTIAL
(Mobile Home Parks)

ELK GROVE TOWNSHIP

SECTION	1960	1964	1966	1970
4	0.0	0.0	0.0	0.0
5	0.0	0.0	0.0	0.0
6	0.0	0.0	0.0	0.0
7	0.0	0.0	0.0	7.0
8	0.0	0.0	0.0	0.0
9	1.1	1.2	2.3	0.0
10	0.0	0.0	0.0	0.0
11	0.0	0.0	0.0	0.0
12	0.0	0.0	0.0	0.0
13	0.0	0.0	0.0	0.0
14	0.0	0.0	0.0	0.0
15	0.0	0.0	0.0	0.0
16	0.0	0.0	0.0	0.0
17	0.0	0.0	0.0	0.0
18	0.0	0.0	0.0	0.0
19	0.0	0.0	0.0	0.0
20	9.1	9.2	8.0	10.0
21	0.0	0.0	0.0	0.0
22	0.0	0.0	0.0	0.0
23	14.1	17.3	10.7	11.8
24	0.0	0.0	0.0	0.0
25	30.8	67.8	36.6	86.4
26	0.0	0.0	0.0	0.0
27	0.0	0.0	0.0	0.0
28	0.0	0.0	0.0	0.0
29	0.0	0.0	0.0	0.0
30	0.0	0.0	0.0	0.0
31	0.0	0.0	0.0	0.0
32	0.0	0.0	0.0	0.0
33	0.0	0.0	0.0	0.0
34	0.0	0.0	0.0	0.0
35	0.0	0.0	0.0	0.0
36	1.2	2.4	1.2	3.6

COMMERCIAL				LEYDEN TOWNSHIP
SECTION	1960	1964	1966	1970
1	8.8	9.2	5.6	12.6
2	26.1	30.0	45.1	62.0
3	13.3	21.2	22.1	28.7
4	0.0	0.0	0.0	5.4
5	0.0	0.0	0.0	0.0
6	0.0	0.0	0.0	0.0
7	0.0	0.0	0.0	0.0
8	0.0	0.0	0.0	0.0
9	0.0	0.0	1.2	11.2
10	4.6	10.8	11.8	9.2
11	8.1	14.2	16.4	20.7
12	21.3	29.7	33.3	32.1
13	48.0	52.1	49.1	55.4
14	10.2	9.7	15.6	22.2
15	10.6	10.1	6.0	18.4
16	12.9	16.8	15.6	18.0
17	17.9	13.3	4.6	5.6
18	0.0	0.0	0.0	7.1
19	0.0	0.0	0.0	0.0
20	4.4	6.0	3.6	2.4
21	18.0	28.8	32.1	28.6
22	12.8	11.9	10.5	10.8
23	2.2	3.5	8.1	5.7
24	22.3	35.1	32.0	40.2
25	47.7	42.5	45.8	57.4
26	27.5	30.7	33.0	51.2
27	26.4	32.2	28.5	34.8
28	45.8	50.8	51.0	47.6
29	10.1	21.3	21.7	15.7
30	2.3	4.7	3.6	3.5
31	3.5	2.3	3.5	3.7
32	13.3	11.9	18.8	17.1
33	8.6	7.0	10.7	7.3
34	28.2	34.2	36.7	32.4
35	49.3	55.9	53.2	26.0
36	33.3	31.9	30.9	33.6

COMMERCIAL				MAINE TOWNSHIP
SECTION	1960	1964	1966	1970
7	24.3	17.9	23.9	35.5
8	14.9	13.9	14.4	11.0
9	0.0	0.0	1.1	0.0
10	0.0	0.0	0.0	1.2
11	8.0	8.6	12.7	15.8
12	17.4	22.0	23.1	24.4
13	0.0	10.8	19.9	13.0
14	72.2	115.1	121.5	108.3
15	1.1	3.8	9.5	6.8
16	11.7	14.0	16.9	17.2
17	69.1	60.8	77.7	81.9
18	5.7	7.0	7.3	15.3
19	51.4	62.6	47.2	56.8
20	25.6	35.4	45.4	67.3
21	16.3	19.5	22.3	26.4
22	2.2	8.3	10.6	9.5
23	7.2	11.7	15.1	17.5
24	16.9	21.4	22.3	26.2
25	27.7	27.5	33.3	27.5
26	33.8	34.8	38.2	42.9
27	8.2	13.0	13.1	10.7
28	28.3	9.8	17.6	23.6
29	5.5	5.2	3.5	32.1
30	8.2	8.6	11.9	0.0
31	0.0	0.0	0.0	0.0
32	22.4	26.0	35.1	41.6
33	14.4	44.3	47.0	55.8
34	3.4	17.5	23.2	23.6
35	30.6	39.6	41.1	38.9
36	40.5	54.2	50.6	53.9

COMMERCIAL				ADDISON TOWNSHIP
SECTION	1960	1964	1966	1970
1	0.0	0.0	0.0	0.0
2	0.0	0.0	0.0	15.8
3	0.0	1.2	2.3	2.0
4	3.6	3.7	2.4	11.6
5	0.0	0.0	0.0	2.3
6	0.0	0.0	0.0	0.0
7	6.1	3.6	19.1	12.4
8	10.5	13.1	10.3	9.4
9	6.0	5.0	14.2	24.4
10	3.5	1.2	2.3	2.3
11	1.2	1.2	0.0	25.9
12	0.0	0.0	0.0	0.0
13	12.7	19.8	7.2	17.0
14	48.5	75.4	67.8	38.4
15	24.3	1.2	25.5	16.9
16	7.0	5.9	1.2	15.4
17	0.0	0.0	0.0	0.0
18	6.9	5.8	5.9	3.8
19	0.0	0.0	0.0	11.2
20	30.9	48.3	32.9	25.0
21	5.8	8.3	11.6	16.9
22	0.0	0.0	0.0	0.0
23	15.2	10.3	9.3	8.1
24	0.0	1.1	2.4	5.2
25	2.4	18.8	20.4	15.6
26	10.2	16.0	13.6	57.5
27	16.3	16.4	18.1	21.8
28	28.1	32.7	39.2	33.5
29	6.7	12.2	5.8	8.9
30	0.0	0.0	0.0	7.5
31	2.4	2.4	2.5	24.8
32	0.0	0.0	1.2	15.5
33	21.6	55.1	46.7	55.5
34	12.9	28.2	23.3	28.3
35	24.2	26.1	32.8	50.2
36	13.0	15.6	17.4	13.2

COMMERCIAL			ELK GROVE	TOWNSHIP
SECTION	1960	1964	1966	1970
4	0.0	0.0	0.0	4.4
5	0.0	0.0	0.0	0.0
6	0.0	0.0	0.0	0.0
7	3.7	0.0	8.2	34.8
8	3.4	2.4	3.4	8.0
9	4.4	3.5	4.5	11.6
10	2.3	0.0	2.3	10.2
11	2.3	1.2	1.2	5.7
12	41.8	36.1	41.4	47.7
13	6.1	17.4	19.1	23.4
14	2.4	17.9	16.5	16.5
15	3.5	6.3	6.0	16.9
16	15.8	17.3	19.7	34.5
17	0.0	0.0	0.0	0.0
18	1.1	2.4	2.3	0.0
19	0.0	0.0	0.0	0.0
20	1.1	0.0	0.0	0.0
21	0.0	14.4	12.6	31.3
22	7.0	11.5	8.2	11.9
23	7.0	47.0	47.5	66.1
24	4.8	7.4	12.6	28.1
25	29.6	32.1	30.7	28.8
26	6.9	8.6	11.9	25.4
27	5.8	6.9	6.7	24.2
28	0.0	0.0	0.0	0.0
29	0.0	0.0	0.0	2.4
30	0.0	0.0	0.0	0.0
31	0.0	0.0	0.0	0.0
32	2.4	5.3	19.3	55.2
33	0.0	0.0	1.1	11.3
34	1.2	0.0	0.0	0.0
35	8.1	10.1	6.1	4.9
36	3.6	4.7	4.7	3.6

INDUSTRIAL				LEYDEN TOWNSHIP
SECTION	1960	1964	1966	1970
1	4.4	3.4	3.4	3.4
2	0.0	0.0	0.0	0.0
3	0.0	0.0	2.3	13.8
4	0.0	0.0	0.0	6.7
5	0.0	0.0	0.0	0.0
6	0.0	0.0	0.0	0.0
7	0.0	0.0	0.0	0.0
8	0.0	0.0	0.0	0.0
9	8.4	20.3	22.2	23.6
10	41.0	66.1	78.8	101.0
11	0.0	0.0	0.0	0.0
12	19.1	21.4	20.7	17.2
13	57.2	62.6	54.9	79.0
14	0.0	0.0	0.0	0.0
15	13.0	15.8	0.0	11.5
16	5.2	6.0	12.0	8.4
17	0.0	0.0	0.0	26.9
18	13.7	18.8	19.0	26.2
19	77.4	126.0	172.4	183.6
20	65.5	77.7	101.6	69.6
21	44.4	58.9	57.1	51.2
22	137.4	170.5	50.3	199.8
23	0.0	0.0	0.0	0.0
24	1.1	1.1	1.1	1.1
25	1.2	1.1	2.3	2.3
26	1.2	2.4	1.2	4.8
27	124.3	129.9	142.5	205.3
28	0.0	0.0	0.0	1.2
29	10.1	8.3	24.1	28.6
30	25.2	47.2	50.2	51.0
31	117.2	129.1	127.8	137.6
32	37.7	57.4	55.2	42.7
33	240.9	232.8	249.9	239.6
34	112.7	119.0	129.1	163.2
35	24.5	27.3	24.8	23.6
36	0.0	0.0	0.0	0.0

INDUSTRIAL				MAINE TOWNSHIP
SECTION	1960	1964	1966	1970
7	0.0	0.0	0.0	0.0
8	5.3	11.6	16.6	27.5
9	0.0	0.0	0.0	0.0
10	0.0	0.0	0.0	0.0
11	0.0	0.0	0.0	0.0
12	0.0	0.0	0.0	0.0
13	0.0	0.0	0.0	0.0
14	0.0	1.2	2.3	7.1
15	0.0	0.0	0.0	0.0
16	16.4	18.6	15.8	17.3
17	34.6	47.7	56.0	49.1
18	41.2	42.1	46.0	44.8
19	14.5	16.2	35.7	66.1
20	9.6	11.8	11.6	8.3
21	5.8	10.3	0.0	4.6
22	0.0	0.0	0.0	0.0
23	0.0	0.0	0.0	0.0
24	0.0	0.0	0.0	0.0
25	0.0	0.0	0.0	0.0
26	1.2	1.2	1.2	0.0
27	0.0	0.0	0.0	0.0
28	0.0	17.2	28.1	41.3
29	4.4	5.9	11.7	16.7
30	64.0	22.4	130.6	165.6
31	5.8	25.5	37.6	46.4
32	3.2	3.5	12.9	32.8
33	4.8	6.2	9.6	9.9
34	4.5	4.7	13.9	14.2
35	0.0	0.0	0.0	0.0
36	4.4	5.8	5.7	6.9

INDUSTRIAL			ADDISON TOWNSHIP	
SECTION	1960	1964	1966	1970
1	0.0	0.0	0.0	0.0
2	8.1	10.1	19.9	36.6
3	0.0	0.0	0.0	0.0
4	0.0	0.0	0.0	0.0
5	0.0	0.0	0.0	0.0
6	0.0	0.0	0.0	0.0
7	0.0	0.0	0.0	6.6
8	0.0	0.0	0.0	0.0
9	0.0	0.0	0.0	0.7
10	0.0	0.0	0.0	0.0
11	12.7	38.0	56.1	57.2
12	0.0	0.0	0.0	0.0
13	17.8	30.9	33.6	34.8
14	10.7	9.4	15.2	8.7
15	10.4	0.0	16.2	6.6
16	0.0	0.0	0.0	0.0
17	0.0	0.0	0.0	0.0
18	0.0	0.0	0.0	0.0
19	0.0	0.0	0.0	0.0
20	0.0	0.0	0.0	0.0
21	0.0	0.0	0.0	0.0
22	0.0	0.0	0.0	0.0
23	0.0	0.0	0.0	0.0
24	29.8	31.0	30.1	32.1
25	0.0	0.0	0.0	0.0
26	0.0	0.0	0.0	50.8
27	0.0	0.0	0.0	0.0
28	11.7	21.8	11.9	3.1
29	0.0	0.0	0.0	0.0
30	0.0	0.0	12.7	36.4
31	0.0	0.0	9.9	24.6
32	19.7	34.9	37.5	43.1
33	42.0	50.4	65.4	101.0
34	0.0	0.0	0.0	0.6
35	2.3	2.4	3.4	16.2
36	0.0	0.0	0.0	0.3

INDUSTRIAL			ELK GROVE	TOWNSHIP
SECTION	1960	1964	1966	1970
4	0.0	0.0	0.0	0.0
5	0.0	0.0	0.0	0.0
6	0.0	0.0	0.0	0.0
7	0.0	0.0	0.0	47.6
8	0.0	0.0	0.0	13.7
9	0.0	0.0	0.0	0.0
10	0.0	0.0	0.0	0.0
11	0.0	0.0	0.0	0.0
12	2.3	4.7	3.4	10.0
13	0.0	0.0	0.0	0.0
14	0.0	0.0	0.0	0.0
15	0.0	0.0	0.0	20.6
16	0.0	8.6	11.6	16.7
17	0.0	0.0	0.0	0.0
18	0.0	0.0	0.0	0.0
19	0.0	0.0	0.0	0.0
20	0.0	0.0	0.0	0.0
21	0.0	0.0	0.0	30.2
22	5.9	35.5	33.9	96.4
23	89.2	129.9	143.8	200.6
24	0.0	0.0	0.0	0.0
25	43.8	57.1	59.0	92.4
26	19.7	61.8	93.0	137.9
27	15.0	11.5	7.9	19.4
28	0.0	0.0	0.0	0.0
29	0.0	0.0	0.0	0.0
30	0.0	0.0	0.0	0.0
31	0.0	0.0	0.0	0.0
32	0.0	0.0	0.0	0.0
33	0.0	0.0	0.0	0.0
34	0.0	0.0	12.3	58.3
35	55.8	145.0	220.4	355.0
36	18.0	18.9	25.9	69.0

WARFHOUSING				LEYDEN TOWNSHIP
SECTION	1962	1964	1966	1970
1	1.1	1.1	1.1	1.1
2	7.1	13.8	13.9	0.0
3	16.9	16.5	19.8	21.8
4	0.0	0.0	0.0	0.0
5	0.0	0.0	0.0	0.0
6	0.0	0.0	0.0	0.0
7	0.0	0.0	0.0	0.0
8	0.0	0.0	0.0	0.0
9	2.4	13.1	32.7	33.5
10	0.0	2.4	7.1	10.3
11	0.0	0.0	0.0	0.0
12	4.5	5.9	3.4	3.4
13	5.7	4.7	4.7	3.5
14	0.0	0.0	0.0	0.0
15	0.0	2.3	0.0	0.0
16	24.5	37.3	39.7	39.6
17	2.2	2.4	7.0	26.9
18	9.1	7.1	8.3	15.5
19	12.2	9.6	14.4	30.0
20	48.0	106.4	130.6	133.2
21	16.8	20.4	23.8	17.8
22	18.6	19.1	8.2	20.5
23	0.0	0.0	0.0	0.0
24	3.3	3.4	4.6	1.1
25	4.7	4.6	6.9	1.1
26	4.8	4.7	5.9	3.6
27	59.1	62.0	61.7	23.2
28	12.7	7.1	4.7	2.3
29	2.2	2.4	16.9	21.4
30	11.5	18.9	23.9	41.8
31	49.2	44.9	53.9	102.9
32	6.7	8.4	9.4	9.8
33	29.7	34.9	35.7	31.5
34	118.6	113.1	152.8	174.0
35	4.7	3.6	3.5	2.4
36	0.0	0.0	0.0	0.0

WAREHOUSING				MAINE TOWNSHIP
SECTION	1960	1964	1966	1970
7	1.1	0.0	0.0	0.0
8	2.1	5.8	13.3	8.8
9	0.0	1.3	0.0	0.0
10	0.0	0.0	0.0	0.0
11	1.1	1.2	0.0	0.0
12	0.0	0.0	0.0	0.0
13	0.0	0.0	0.0	0.0
14	1.2	1.2	2.3	0.0
15	0.0	0.0	0.0	0.0
16	1.2	1.2	4.5	0.0
17	17.8	14.3	18.3	21.1
18	0.0	0.0	2.4	28.3
19	0.0	0.0	0.0	12.8
20	4.3	2.4	3.5	1.2
21	0.0	1.1	5.9	0.0
22	0.0	0.0	0.0	0.0
23	1.1	2.3	4.6	0.0
24	0.0	0.0	0.0	0.0
25	2.4	1.2	0.0	0.0
26	8.5	6.0	10.4	0.0
27	0.0	0.0	0.0	0.0
28	2.5	0.0	5.9	2.4
29	0.0	7.1	18.7	20.2
30	0.0	2.5	16.6	36.0
31	0.0	0.0	0.0	14.6
32	0.0	0.0	21.1	16.4
33	1.2	3.7	3.6	1.2
34	4.5	4.7	2.3	0.0
35	0.0	0.0	0.0	0.0
36	9.9	6.9	4.6	4.6

WAREHOUSING			ADDISON TOWNSHIP	
SECTION	1960	1964	1966	1970
1	0.0	0.0	0.0	0.0
2	0.0	1.3	1.2	1.5
3	0.0	1.2	2.3	0.0
4	0.0	5.0	4.7	0.0
5	0.0	0.0	0.0	0.0
6	0.0	0.0	0.0	0.0
7	0.0	2.4	8.4	0.0
8	3.5	7.1	2.3	0.0
9	0.0	1.3	0.0	0.0
10	0.0	0.0	0.0	0.0
11	0.0	5.9	19.0	1.1
12	0.0	0.0	0.0	1.4
13	2.5	14.8	15.6	0.0
14	0.0	0.0	0.0	1.4
15	0.0	0.0	0.0	0.2
16	0.0	0.0	0.0	0.0
17	3.5	3.4	1.1	0.0
18	0.0	0.0	0.0	0.0
19	0.0	0.0	0.0	0.0
20	2.3	1.2	0.0	0.0
21	0.0	0.0	0.0	0.0
22	0.0	0.0	0.0	0.0
23	0.0	0.0	0.0	0.0
24	10.7	5.7	7.2	0.0
25	0.0	0.0	6.0	0.0
26	0.0	1.2	14.0	9.3
27	3.5	0.0	0.0	0.0
28	0.0	0.0	1.2	0.0
29	0.0	0.0	0.0	0.0
30	0.0	0.0	5.8	4.1
31	0.0	3.6	5.0	6.7
32	6.0	18.0	23.4	6.6
33	10.8	10.5	14.0	7.6
34	0.0	0.0	0.0	0.0
35	5.8	0.0	0.0	0.2
36	0.0	0.0	0.0	0.0

WAREHOUSING			ELK GROVE	TOWNSHIP
SECTION	1960	1964	1966	1970
4	0.0	0.0	0.0	0.0
5	0.0	0.0	0.0	0.0
6	0.0	0.0	0.0	0.0
7	0.0	0.0	0.0	0.0
8	0.0	0.0	0.0	0.0
9	0.0	0.0	0.0	0.0
10	0.0	0.0	4.7	0.0
11	0.0	0.0	0.0	0.0
12	0.0	0.0	0.0	0.0
13	0.0	0.0	0.0	0.0
14	0.0	2.6	0.0	0.0
15	0.0	0.0	0.0	0.0
16	0.0	0.0	0.0	0.0
17	0.0	0.0	0.0	0.0
18	0.0	0.0	0.0	0.0
19	0.0	0.0	0.0	0.0
20	0.0	0.0	0.0	0.0
21	0.0	0.0	0.0	0.0
22	1.2	0.0	7.0	0.0
23	9.4	5.2	8.3	0.0
24	0.0	0.0	0.0	0.0
25	3.6	9.5	13.0	0.0
26	1.2	6.2	10.7	33.9
27	0.0	0.0	0.0	27.8
28	8.2	0.0	0.0	0.0
29	0.0	0.0	0.0	0.0
30	0.0	0.0	0.0	0.0
31	0.0	0.0	0.0	0.0
32	0.0	13.3	9.1	0.0
33	0.0	0.0	0.0	0.0
34	0.0	5.8	16.8	102.3
35	45.3	102.1	140.4	64.7
36	32.4	43.7	43.5	0.0

INSTITUTIONAL			LEYDEN TOWNSHIP	
SECTION	1960	1964	1966	1970
1	144.6	142.5	145.3	133.1
2	25.0	27.7	20.8	26.4
3	0.0	0.0	0.0	29.8
4	16.6	18.7	15.6	21.4
5	0.0	0.0	0.0	0.0
6	0.0	0.0	0.0	0.0
7	0.0	0.0	0.0	0.0
8	0.0	0.0	0.0	9.4
9	0.0	0.0	0.0	0.0
10	0.0	0.0	0.0	0.0
11	10.4	16.6	18.7	20.7
12	16.8	13.1	13.8	12.6
13	29.7	52.4	54.9	41.3
14	13.2	8.5	9.6	18.7
15	0.0	0.0	47.0	0.0
16	7.8	8.4	8.4	7.2
17	0.0	0.0	0.0	0.0
18	0.0	0.0	0.0	0.0
19	0.0	0.0	0.0	0.0
20	4.4	0.0	0.0	0.0
21	25.2	21.6	33.3	28.6
22	3.5	3.5	0.0	3.6
23	14.2	17.5	12.7	10.3
24	3.3	5.7	8.0	9.2
25	9.3	12.6	11.5	6.0
26	8.4	30.7	33.0	27.4
27	6.3	6.0	5.9	5.8
28	16.6	23.6	16.6	15.1
29	5.6	7.1	4.8	9.5
30	39.0	35.4	38.3	37.1
31	16.4	12.7	12.9	17.4
32	11.1	9.6	15.3	11.0
33	6.2	5.8	5.9	6.0
34	11.7	17.7	17.8	21.6
35	30.5	27.3	26.0	49.6
36	8.0	7.1	5.7	8.1

INSTITUTIONAL			MAINE TOWNSHIP	
SECTION	1960	1964	1966	1970
7	14.3	22.7	25.0	20.0
8	27.6	33.5	34.2	37.4
9	0.0	0.0	0.0	0.0
10	0.0	0.0	0.0	2.4
11	6.9	15.9	16.2	15.8
12	25.5	22.0	24.2	26.7
13	2.5	13.2	14.0	11.8
14	36.1	40.8	38.6	36.9
15	16.0	21.3	23.7	39.9
16	11.7	14.0	19.2	13.8
17	6.7	7.1	9.1	8.2
18	3.4	2.3	10.9	16.5
19	22.4	25.5	24.2	23.2
20	7.5	18.8	15.1	14.2
21	2.3	0.0	1.2	0.0
22	110.0	99.8	102.6	103.5
23	25.8	45.5	38.3	40.9
24	36.0	30.9	32.9	35.7
25	10.8	15.5	21.4	19.5
26	8.5	12.0	6.9	24.4
27	19.9	22.5	26.2	20.2
28	16.0	17.2	18.7	16.5
29	25.5	17.7	21.0	30.9
30	76.9	77.3	71.2	76.8
31	0.0	0.0	0.0	0.0
32	0.0	0.0	0.0	0.0
33	6.0	7.4	4.8	7.4
34	11.2	10.5	47.6	69.6
35	24.7	28.8	27.0	27.1
36	8.8	9.2	10.3	11.5

INSTITUTIONAL ADDISON TOWNSHIP

SECTION	1960	1964	1966	1970
1	0.0	0.0	0.0	0.0
2	0.0	3.8	4.7	4.1
3	0.0	0.0	0.0	0.0
4	1.2	0.0	0.0	0.0
5	0.0	0.0	0.0	1.4
6	0.0	8.4	6.9	7.1
7	0.0	0.0	1.2	0.4
8	15.1	30.9	22.9	31.3
9	1.2	2.5	0.0	3.3
10	5.9	4.9	3.5	7.0
11	6.9	10.7	9.3	14.0
12	0.0	0.0	0.0	0.0
13	1.3	2.5	4.8	2.4
14	58.2	56.6	60.8	79.5
15	1.2	12.9	3.5	1.5
16	5.8	10.5	13.2	21.2
17	0.0	1.1	1.1	2.1
18	0.0	0.0	7.0	0.0
19	1.1	3.4	14.8	34.2
20	0.0	14.5	23.2	17.9
21	0.0	4.8	0.0	3.4
22	0.0	0.0	0.0	2.8
23	19.6	20.6	23.3	23.5
24	15.5	10.3	9.6	3.4
25	10.8	13.8	10.8	12.9
26	11.4	7.4	11.1	6.8
27	0.0	1.2	1.1	0.4
28	32.8	55.7	43.9	35.7
29	0.0	4.9	5.8	6.9
30	0.0	1.2	2.3	40.9
31	0.0	0.0	0.0	20.0
32	0.0	0.0	0.0	36.9
33	13.2	12.9	15.2	11.3
34	5.9	11.7	12.8	10.6
35	6.9	14.2	14.7	9.5
36	4.7	2.4	2.3	6.5

INSTITUTIONAL ELK GROVE TOWNSHIP

SECTION	1960	1964	1966	1970
4	8.3	5.0	9.5	8.0
5	4.7	5.2	5.2	5.9
6	0.0	0.0	0.0	0.0
7	0.0	0.0	0.0	0.0
8	51.2	47.6	50.8	54.7
9	74.3	73.9	71.5	99.8
10	0.0	7.0	4.7	59.9
11	28.8	23.0	20.8	20.5
12	43.0	50.1	36.8	13.3
13	0.0	6.2	19.1	14.0
14	21.5	28.1	47.3	43.7
15	0.0	43.9	45.8	46.0
16	0.0	0.0	0.0	5.9
17	0.0	0.0	0.0	0.0
18	0.0	0.0	0.0	0.0
19	0.0	0.0	0.0	0.0
20	0.0	0.0	0.0	0.0
21	0.0	0.0	0.0	0.0
22	0.0	0.0	0.0	0.0
23	0.0	0.0	0.0	0.0
24	7.2	11.1	16.1	26.9
25	1.2	2.4	1.2	0.0
26	0.0	0.0	0.0	0.0
27	0.0	0.0	0.0	2.4
28	25.8	37.8	78.6	52.1
29	0.0	0.0	21.8	14.4
30	0.0	0.0	0.0	0.0
31	0.0	0.0	0.0	0.0
32	0.0	11.9	27.3	63.2
33	0.0	17.0	25.7	28.8
34	0.0	0.0	0.0	0.0
35	0.0	0.0	0.0	0.0
36	0.0	0.0	0.0	0.0

T.C.U.				LEYDEN TOWNSHIP
SECTION	1960	1964	1966	1970
1	124.7	141.4	141.9	166.4
2	164.0	193.8	180.6	142.3
3	187.3	188.3	182.1	210.0
4	494.0	514.5	500.7	501.2
5	658.8	658.8	658.8	658.8
6	513.6	513.6	513.6	513.6
7	503.3	503.3	503.3	503.4
8	638.3	638.3	683.3	628.9
9	424.2	436.6	433.8	476.2
10	22.8	10.8	14.1	12.6
11	47.5	62.9	53.8	81.5
12	116.8	117.5	113.8	96.4
13	73.2	30.3	101.7	92.0
14	55.6	67.8	70.6	69.0
15	58.9	52.9	45.8	62.0
16	317.8	309.0	303.0	343.2
17	542.1	541.3	546.4	491.7
18	405.1	393.9	402.4	408.2
19	121.6	128.4	128.1	156.0
20	227.1	216.4	208.0	313.2
21	118.7	122.1	122.6	148.7
22	50.1	51.3	67.9	45.7
23	84.2	74.7	65.9	79.2
24	154.7	131.4	99.3	94.1
25	149.0	167.8	135.2	176.7
26	63.3	70.9	74.3	65.4
27	118.0	119.2	124.7	104.4
28	124.8	102.8	109.1	127.6
29	56.1	73.2	55.5	82.1
30	109.0	132.2	107.7	127.6
31	107.8	124.5	124.3	114.1
32	73.3	109.9	116.3	109.8
33	66.7	83.8	48.8	81.1
34	104.5	134.3	107.8	105.6
35	36.4	22.6	39.0	42.5
36	104.6	132.3	165.5	110.2

T.C.U.				MAINE TOWNSHIP
SECTION	1960	1964	1966	1970
7	78.3	112.3	96.6	111.0
8	76.5	64.7	65.2	57.2
9	65.8	58.6	64.0	94.4
10	44.5	28.1	37.4	47.2
11	70.9	94.3	83.3	94.9
12	37.1	58.7	55.4	91.6
13	104.1	163.8	129.8	185.3
14	56.6	59.9	59.6	110.7
15	25.1	62.5	33.2	65.0
16	76.0	67.6	84.7	100.0
17	103.7	129.9	104.0	209.4
18	70.9	85.6	83.5	153.4
19	45.8	70.8	72.5	92.8
20	93.8	108.2	96.7	145.3
21	95.3	117.1	112.4	116.1
22	59.5	91.5	77.8	89.2
23	26.9	42.0	43.0	73.7
24	153.0	123.8	143.3	119.0
25	109.5	137.3	96.2	151.5
26	89.4	93.5	76.4	83.5
27	79.6	94.8	94.0	133.3
28	87.5	99.4	92.5	118.0
29	62.1	76.8	84.1	85.7
30	71.0	61.3	79.5	62.4
31	487.4	483.3	508.9	485.6
32	432.3	450.7	465.7	472.5
33	133.3	144.0	138.6	163.7
34	53.9	39.6	72.0	67.3
35	107.2	133.2	166.6	165.2
36	112.8	116.5	147.2	126.2

T.C.U. ADDISON TOWNSHIP

SECTION	1960	1964	1966	1970
1	628.8	628.8	628.8	623.4
2	10.5	7.5	19.9	43.7
3	78.0	84.4	87.6	111.5
4	32.3	39.8	34.4	50.9
5	9.3	18.8	23.2	39.2
6	55.9	59.8	57.6	76.2
7	31.7	22.6	25.1	39.3
8	73.2	58.2	77.9	132.5
9	65.8	62.2	63.9	78.6
10	49.3	53.6	60.8	118.7
11	8.1	11.9	21.0	65.7
12	637.6	640.0	640.0	609.8
13	141.0	155.9	149.8	179.5
14	72.3	73.1	81.9	131.8
15	39.3	42.2	55.6	126.9
16	45.5	36.3	32.4	65.6
17	31.4	42.4	37.6	63.7
18	29.8	32.3	27.0	43.4
19	6.8	17.1	33.0	63.2
20	25.1	37.4	47.5	92.5
21	25.7	39.3	35.8	73.7
22	31.6	17.6	28.1	74.9
23	33.7	34.4	29.1	86.2
24	28.6	46.0	45.8	86.2
25	63.4	71.3	82.7	126.6
26	36.4	48.1	49.3	113.0
27	70.9	67.9	64.5	206.1
28	56.7	83.5	103.3	132.8
29	20.0	41.5	41.8	87.9
30	29.1	23.6	53.1	54.5
31	57.1	56.6	59.4	69.0
32	56.7	56.5	63.3	101.5
33	73.2	72.7	77.1	170.1
34	42.1	47.0	51.3	125.4
35	77.1	122.3	128.0	169.6
36	50.8	112.9	92.6	141.5

T.C.U. ELK GROVE TOWNSHIP

SECTION	1960	1964	1966	1970
4	0.0	0.0	0.0	0.0
5	1.9	2.1	1.0	3.0
6	0.0	10.1	5.0	17.6
7	22.4	94.6	111.3	110.2
8	29.6	36.9	40.7	63.8
9	13.3	25.1	26.1	97.4
10	44.3	57.1	54.7	65.5
11	92.2	84.8	99.3	110.6
12	124.4	145.6	137.9	125.4
13	86.4	102.9	157.9	163.8
14	55.0	72.8	126.5	119.2
15	46.3	30.1	109.7	72.6
16	48.6	58.0	71.8	76.2
17	13.9	20.0	17.3	17.5
18	13.5	20.4	14.1	6.9
19	21.4	22.8	0.0	1.2
20	9.1	13.9	27.3	5.0
21	30.3	44.3	81.5	46.4
22	52.9	68.7	140.4	85.7
23	16.4	47.0	84.4	28.3
24	79.2	135.1	169.7	108.8
25	133.8	134.3	195.9	138.0
26	53.2	60.5	60.8	85.9
27	31.2	44.7	86.5	102.8
28	90.3	83.8	78.6	112.8
29	9.2	9.2	47.3	50.4
30	6.9	8.9	20.2	8.3
31	10.6	9.9	25.3	23.4
32	7.1	22.5	48.8	89.7
33	76.7	112.7	154.3	178.8
34	28.8	26.5	58.3	101.1
35	38.4	45.4	37.5	80.5
36	335.6	348.3	348.2	370.3

VAC, AGRICULTURE				LEYDEN TOWNSHIP
SECTION	1960	1964	1966	1970
1	36.4	16.1	21.4	10.3
2	146.2	114.2	93.8	70.0
3	111.2	115.4	92.2	57.4
4	102.1	67.3	62.6	21.4
5	0.0	0.0	0.0	0.0
6	0.0	0.0	0.0	0.0
7	0.0	0.0	0.0	0.0
8	0.0	0.0	0.0	0.0
9	167.3	139.6	102.6	48.4
10	95.6	69.7	43.5	21.8
11	316.1	259.7	217.7	142.3
12	32.6	8.3	4.6	1.1
13	64.1	28.0	23.4	3.5
14	184.4	113.8	93.4	59.7
15	18.8	18.0	395.4	1.1
16	86.5	66.1	52.9	14.4
17	75.0	80.1	80.4	29.1
18	58.5	70.6	55.7	39.3
19	323.5	249.6	196.3	141.6
20	289.3	230.7	194.7	122.4
21	152.3	69.7	52.4	33.3
22	95.5	62.0	430.7	31.3
23	13.1	5.8	4.6	0.0
24	11.1	7.9	5.7	5.7
25	9.3	12.6	6.9	3.4
26	21.5	17.7	43.6	2.0
27	55.2	51.2	35.6	9.3
28	58.8	67.3	60.5	36.0
29	141.3	106.3	95.2	36.9
30	181.3	113.3	106.5	77.7
31	119.6	121.0	120.7	70.7
32	62.2	28.7	23.5	17.1
33	50.7	43.1	29.7	16.9
34	205.4	173.2	135.0	75.6
35	50.5	48.7	49.7	42.5
36	9.2	5.9	5.7	0.0

VAC, AGRICULTURE				MAINE TOWNSHIP
SECTION	1960	1964	1966	1970
7	94.8	111.1	102.3	77.7
8	154.1	145.7	140.2	155.1
9	259.9	284.1	276.6	177.0
10	189.0	156.4	138.3	95.6
11	189.7	104.2	107.5	73.4
12	53.4	26.9	20.8	7.0
13	193.6	68.6	31.6	3.5
14	292.4	203.8	161.2	70.2
15	436.6	299.0	214.3	75.2
16	152.0	147.9	125.4	36.8
17	181.7	153.7	144.0	51.5
18	237.9	191.9	186.4	92.0
19	224.5	174.0	164.5	104.4
20	113.0	105.8	90.9	56.6
21	93.0	67.7	63.2	42.5
22	133.6	92.3	97.9	47.6
23	328.0	136.4	101.0	30.4
24	67.5	16.7	2.3	0.0
25	39.7	28.7	22.6	20.7
26	58.0	65.9	57.9	7.0
27	83.1	59.3	30.9	10.7
28	83.8	79.8	52.7	40.1
29	215.3	138.2	97.0	45.2
30	280.5	241.7	191.1	138.0
31	52.1	37.6	0.0	0.0
32	106.5	121.8	62.0	17.6
33	146.5	121.8	95.2	60.8
34	125.9	113.0	48.7	1.2
35	10.6	4.8	9.4	2.0
36	28.5	11.5	6.9	0.0

VAC,AGRICULTURE ADDISON TOWNSHIP

SECTION	1960	1964	1966	1970
1	0.0	0.0	0.0	5.4
2	583.0	556.7	545.4	502.4
3	489.6	465.0	447.5	432.1
4	473.2	449.7	463.7	478.1
5	547.8	542.0	524.7	524.4
6	354.0	340.9	337.6	336.5
7	361.3	360.8	327.3	312.2
8	157.3	169.8	123.6	103.4
9	489.3	459.3	482.7	449.1
10	312.4	288.9	250.4	229.2
11	419.7	363.3	336.4	301.8
12	0.0	0.0	0.0	22.5
13	349.2	282.1	279.3	262.5
14	159.9	114.3	98.2	140.4
15	411.4	279.0	226.9	219.3
16	353.2	293.0	209.7	124.7
17	580.8	547.3	520.4	479.7
18	378.9	352.6	358.1	340.2
19	417.7	408.6	369.9	227.4
20	460.5	370.7	325.4	268.5
21	310.7	248.6	239.1	194.7
22	427.8	434.9	363.9	361.9
23	88.0	68.8	69.9	36.1
24	325.1	305.6	250.7	231.0
25	229.7	190.0	133.0	135.6
26	521.8	501.9	477.2	348.5
27	378.7	365.0	353.9	259.0
28	278.5	200.8	204.2	191.7
29	484.4	410.4	397.2	290.2
30	392.3	358.0	300.0	231.8
31	394.9	395.0	375.2	324.8
32	483.5	443.7	438.2	394.6
33	297.7	290.7	239.4	161.8
34	373.2	294.8	280.9	230.0
35	223.3	182.8	164.2	121.0
36	124.0	72.0	62.5	103.8

VAC,AGRICULTURE ELK GROVE TOWNSHIP

SECTION	1960	1964	1966	1970
4	9.5	11.3	5.9	1.8
5	27.1	18.9	17.8	16.8
6	31.6	17.6	8.8	0.0
7	260.5	254.5	214.3	134.6
8	529.2	502.6	462.1	319.2
9	487.2	423.3	362.1	142.7
10	414.1	348.2	297.9	126.6
11	72.6	43.6	50.8	22.8
12	68.6	37.3	48.3	20.0
13	377.1	132.7	71.8	32.8
14	419.6	291.1	225.7	168.7
15	555.7	505.7	343.6	233.5
16	276.0	257.8	235.0	213.0
17	15.0	20.0	12.7	16.3
18	12.4	9.6	17.6	87.4
19	0.0	0.0	0.0	49.1
20	0.0	0.0	0.0	30.0
21	122.4	111.9	104.4	60.3
22	528.6	462.7	399.1	348.7
23	472.3	351.3	322.1	308.0
24	398.6	222.3	142.2	52.6
25	347.0	282.9	263.2	288.0
26	512.6	464.6	413.5	315.8
27	575.4	524.3	486.3	418.7
28	128.3	95.6	61.5	21.1
29	347.2	271.2	228.2	134.4
30	124.6	112.2	119.9	121.5
31	293.7	290.0	246.3	263.2
32	626.4	544.9	411.1	151.8
33	346.3	181.8	120.8	102.5
34	592.2	585.9	534.7	359.4
35	481.3	330.3	236.1	136.6
36	216.3	186.6	178.8	171.8

REC,OPEN,WATER LEYDEN TOWNSHIP

SECTION	1960	1964	1966	1970
1	6.6	6.9	5.6	3.4
2	2.4	1.2	0.0	1.1
3	349.2	340.2	351.3	328.7
4	0.0	0.0	0.0	12.1
5	0.0	0.0	0.0	0.0
6	0.0	0.0	0.0	0.0
7	0.0	0.0	0.0	0.0
8	0.0	0.0	0.0	0.0
9	0.0	0.0	0.0	0.0
10	488.1	485.6	488.2	484.3
11	1.2	0.0	0.0	0.0
12	19.1	22.5	19.5	19.5
13	97.2	103.7	100.5	102.6
14	229.3	292.9	292.1	291.3
15	425.1	421.9	0.0	415.4
16	51.7	52.9	51.7	54.0
17	0.0	0.0	0.0	58.2
18	5.7	7.1	4.9	4.8
19	0.0	0.0	0.0	0.0
20	0.0	0.0	0.0	0.0
21	15.6	15.6	16.7	11.9
22	256.1	258.8	19.9	257.6
23	334.4	319.7	329.5	328.2
24	102.4	100.8	106.2	114.8
25	5.8	4.6	4.6	0.0
26	361.9	333.1	272.4	255.8
27	43.9	44.1	49.9	42.9
28	14.0	15.4	16.6	13.9
29	1.1	4.7	4.8	4.8
30	55.1	59.0	52.6	53.4
31	59.8	50.7	23.4	24.8
32	2.2	1.2	1.2	2.4
33	3.7	0.0	2.4	2.4
34	1.2	0.0	0.0	0.0
35	407.2	414.8	401.9	427.2
36	94.3	92.1	92.4	77.7

REC,OPEN,WATER MAINE TOWNSHIP

SECTION	1960	1964	1966	1970
7	3.3	4.8	5.7	2.2
8	266.8	270.5	261.7	243.1
9	195.2	162.9	169.2	213.6
10	214.5	212.6	200.7	194.7
11	0.0	0.0	1.2	3.4
12	29.0	24.5	21.9	24.4
13	2.5	7.2	8.2	8.3
14	1.2	7.2	7.0	13.1
15	16.0	45.0	47.4	38.8
16	285.2	279.5	267.7	326.6
17	1.1	5.9	4.6	8.2
18	9.2	10.5	10.9	16.5
19	3.4	3.5	2.3	1.2
20	0.0	0.0	0.0	0.0
21	275.5	273.2	257.0	274.8
22	37.1	21.4	7.1	7.1
23	61.7	230.8	231.1	241.0
24	6.7	45.4	44.6	42.8
25	10.8	10.7	10.7	12.6
26	125.6	131.9	133.1	129.9
27	98.3	94.8	83.3	92.8
28	235.4	234.5	236.6	224.2
29	71.2	94.5	92.3	80.9
30	0.0	0.0	0.0	0.0
31	0.0	0.0	0.0	0.0
32	0.0	0.0	8.2	7.6
33	36.0	46.8	42.2	34.7
34	298.8	291.2	297.1	266.7
35	10.6	10.8	11.7	10.6
36	23.0	18.5	20.7	19.5

REC,OPEN,WATER ADDISON TOWNSHIP

SECTION	1960	1964	1966	1970
1	0.0	0.0	0.0	0.0
2	0.0	0.0	0.0	1.1
3	0.0	0.0	0.0	0.0
4	36.0	90.7	89.0	62.5
5	0.0	0.0	0.0	0.0
6	1.2	0.0	1.2	0.0
7	0.0	1.2	1.2	8.3
8	132.4	123.5	128.2	114.5
9	15.6	23.8	13.0	9.1
10	0.0	0.0	2.3	0.0
11	149.9	163.9	150.7	136.5
12	0.0	0.0	0.0	6.3
13	0.0	0.0	0.0	1.4
14	58.0	57.8	44.4	8.9
15	4.6	143.0	41.7	16.3
16	142.5	139.5	218.1	207.9
17	0.0	0.0	0.0	0.0
18	0.0	0.0	0.0	4.6
19	0.0	0.0	0.0	10.1
20	2.3	32.2	36.6	31.0
21	237.1	237.9	234.5	227.5
22	63.3	69.2	80.7	48.9
23	255.3	269.5	262.3	282.3
24	58.4	67.8	74.7	71.5
25	232.9	225.0	225.3	208.1
26	2.3	4.9	1.2	0.6
27	1.2	2.3	0.0	6.2
28	1.2	3.6	0.0	5.7
29	45.6	44.0	49.9	45.6
30	0.0	0.0	0.0	0.0
31	2.4	0.0	3.7	0.0
32	16.2	13.2	17.6	3.7
33	0.0	0.0	2.3	5.1
34	0.0	0.0	0.0	8.1
35	8.1	0.0	0.0	10.4
36	255.1	247.4	250.0	195.5

REC,OPEN,WATER ELK GROVE TOWNSHIP

SECTION	1960	1964	1966	1970
4	0.0	0.0	0.0	0.0
5	0.0	0.0	0.0	0.0
6	0.0	0.0	0.0	0.0
7	0.0	0.0	0.0	0.0
8	0.0	0.0	0.0	9.1
9	0.0	0.0	10.2	0.0
10	0.0	0.0	0.0	18.1
11	133.7	134.5	132.8	126.5
12	4.6	4.7	2.3	25.5
13	0.0	8.7	0.0	11.7
14	2.4	2.6	2.4	0.0
15	0.0	0.0	0.0	0.0
16	256.0	245.7	242.0	240.4
17	611.2	601.2	611.1	608.8
18	344.4	342.5	339.6	280.6
19	350.3	361.2	381.4	335.8
20	611.3	607.5	597.6	583.8
21	420.1	399.9	401.6	407.2
22	21.1	20.6	19.9	20.2
23	0.0	3.7	3.6	0.0
24	0.0	0.0	0.0	0.0
25	46.2	48.7	35.4	0.0
26	0.0	0.0	1.2	0.0
27	0.0	0.0	0.0	0.0
28	143.0	144.0	157.2	151.3
29	272.4	327.3	319.2	357.6
30	268.6	281.2	261.1	271.4
31	101.4	97.5	112.8	90.1
32	0.0	0.0	0.0	2.3
33	0.0	12.1	7.8	8.8
34	0.0	0.0	0.0	0.0
35	0.0	0.0	0.0	0.0
36	0.0	0.0	0.0	0.0

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